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LAND APPLICATION OF WASTEWATER

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LAND APPLICATION OF WASTEWATER

Proceedings of a Research Symposium Sponsored
by the
United States Environmental Protection Agency, Region III

John M. Clayton Hall
University of Delaware
Newark, Delaware
November 20-21, 1974

Published by the
United States Environmental Protection Agency, Region III
Daniel J. Snyder III, Regional Administrator

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EPA Guidance and Policy on Land Treatment

by
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I am pleased to participate in this symposium on land application of wastewater because of the importance of it's theme. It focuses on an area of technology that has been with us for many decades but has recently gained importance due to the awareness of environmental issues.

It is encouraging to see state, county and municipal engineers, consulting engineers, municipal officials, members of university facilities and conservationist groups here to become acquainted with the current state of the act, recent technical advances and actual field experience in disposal of municipal effluents.

I must commend Dan Snyder and his Region III staff for initiating the planning and implementing the 2 day symposium. A very fine program has been put together in an effort to provide Region III people current information.

From my view, the concept of recycling as a conservation practice, appealing as it may be, has been in conflict with the throw-away philosophy of our society in which planned obsolescence has become a way of life. If we, as a society, have such a disregard for the value of material things, how, can we convince people that recycling of such an unappealing material such as sewage is a valuable alternative. One of the ways is through a symposium such as this which can capitalize on what I sense is the beginning of a change in national attitude. There is new concern for the environment; there is new concern for conservation of energy; and there is a growing recognition that our resources are finite. These are only a few of the trends that combine at this point in time to make the task of gaining public acceptance of this concept of utilization of wastes as opposed to disposing of them.

Aside from posing my philosophical concerns, I see my role as an EPA headquarters participant in this symposium as providing you with an insight to EPA policy and guidance.

The Water Pollution Control Act Amendments of 1972 gives us a firm base from which to work and to encourage land treatment. Title II of the act entitled "grants for construction of treatment works" states that "waste treatment management plans and practices *shall provide* for the application of the "best practicable waste treatment" technology before any discharge into receiving waters, including reclaiming and recycling of water and confined disposal of pollutants so they will not migrate to cause water or other environmental pollution and shall provide for consideration of advanced waste treatment technique," Title II further states "the administrator shall encourage waste treatment management which results in the construction of revenue producing facilities for (1) the recycling of potential sewage pollutants through the production of agriculture, silva culture, or aquaculture products or any combination thereof; (2) the combined and contained disposal of pollutants not recycled; (3) the reclamation of wastewater; and (4) the ultimate disposal of sludge in a manner that will not result in environmental hazards." The act goes on to state "the administrator shall encourage waste treatment management, which results in integrating facilities to treat, dispose of, or utilize other industrial wastes." Section 208 of Title II provides for the development of area wide waste treatment management plans and requires that such plan will provide for any requirements for the acquisition of *Land for treatment purposes*.

Section 403 of the act instructs the administrator among other things to develop *other* possible locations and methods of disposal or recycling of pollutants, including land base alternatives.

Using these sections of the act as our guidance we, I feel, have responded thru promulgating various regulations, guidance documents and technical bulletins that include land treatment as an integral part. I would like to develop our guidance and direction by looking briefly at these documents and examining our current activities.

The document entitled "Alternative Waste Management Techniques for Best Practicable Waste Treatment" was proposed for public comment in March 1974. Comments have been received, revisions will be made and it is anticipated the final version will appear in the Federal Register prior to January 1975.

The document identifies the currently known techniques for meeting the BPT requirements. A substantial portion of the document contains information on land application and treatment techniques.

The choice of which alternative to adopt is left to each municipality or regional sanitary district. If it receives federal funds, however, it must be guided by the agency's cost effectivenss regulations. I will add that in these cost effectiveness regulations it specifically states that "all feasible alternative waste management systems shall be identified. These alternatives should include. . . .systems using land or surface disposal. .".

Once one alternative is selected, it must comply with certain additional requirements. Any land application or land utilization techniques must, in order to qualify for federal funding, comply with criteria designed to protect ground waters. These criteria are intended to ensure that ground water resources remain suitable for drinking water purposes. The ground waters in the zone of saturation resulting from land or surface disposal must meet the chemical and pesticide level in the EPA public drinking water criteria "Manual for Evaluating Public Drinking Water." Other criteria have been developed but will not be discussed for brevity.

With the anticipation of a large number of construction grant applications for land treatment systems being forwarded to the regional offices, as a result of the Act, the technical bulletin "Evaluation of Land Application Systems" was developed. It provides information and program guidance to EPA regional offices for analyzing and evaluating municipal applications for federal grant for the construction of publically owned treatment works using land application methods. It also provides information and assistance to other federal agencies, to interstate organizations, to state water pollution control agencies, to the wastewater industry and to consultants and designers of land application systems.

An evaluation checklist and background information are provided, and procedures are given for evaluating alternatives dealing with crop irrigation, infiltration percolations, overland flow or combinations of these systems. Systems involving injection wells, sealed evaporation ponds, or septic tank leach fields for wastewater disposal are exluded.

Another document is being prepared for EPA on costs of land application systems. This will provide means and information for determining costs for land treatment systems so they can be compared with other systems on the basis of cost effectiveness. Cost components, land requirements, and cost curves will be developed for two stages of planning, preliminary and detailed, for each major type of land treatment system (irrigation, overland flow and infiltration-percolation. Examples of cost calculation will also be included.

When completed, this document along with the technical bulletin on evaluation procedures will give, I feel, the regional offices adequate technical information for a complete and thorough review of proposed land treatment projects.

In order to emphasize that land treatment should be given full and adequate consideration, a memorandum was sent to each regional administrator from John Quarles, Deputy Administrator, EPA. This memorandum requested that the regional review of application for construction of publically owned treatment works require that land application be considered as an alternative waste management system.

The instructions to the regional administrators also indicated that if it can be demonstrated that land treatment is the most cost effective alternative, is consistent with the environmental assessment, and in other aspects satisfies applicable tests, the region will insist that land treatment be used in lieu of other systems of waste management.

I think the guidance is clear and straight forward. It will be up to the regions to insure that adequate treatment is given to land application or land utilization techniques and it will be up to the design engineers to include the land treatment alternative in all projects proposed to be federally funded.

Land Application Research at Robert S. Kerr Environmental Research Laboratory

by

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INTRODUCTION

The Water Quality Control Branch (WQCB) of the Robert S. Kerr Environmental Research Laboratory (RSKERL) has been assigned Environmental Protection Agency (EPA) responsibility for research to utilize agriculture, silviculture, or aquaculture projects for management of municipal wastewaters. The major focus of this integrated research program is the development of a reliable data base which establishes the cans and cannots of these approaches with respect to the goals of the Water Pollution Control Act of 1972 (PL 92-500). The transition from strictly land application through wetland systems to strictly aquaculture systems is a gradual change and all of these systems are influenced by similar scientific principles. For this reason, this discussion of land application will cover some concepts which some people would consider as more aquatic than agronomic in nature.

The EPA is a young agency which was formed by Executive action in December 1970. Historically, the involvement of the WQCB in research on land application of municipal wastewaters predates the formation of EPA by many years. Projects supported by predecessor agencies, including the Federal Water Quality Administration, the Federal Water Pollution Control Administration, and the U.S. Public Health Service, are an integral part of technical data base being developed by the WQCB. The results of these projects conducted under the auspices of predecessor agencies provide much of the current data base and serve as the principal guides for the direction of present and future research goals.

The major thrust of current research efforts is a quantitative assessment of the capability of existing land application approaches to meet the goals of PL 92-500. Hundreds of facilities which are in current use serve as readily available sites for research evaluation. The variety of climatic conditions, system ages, and site management practices available at these sites cannot be duplicated in the laboratory or through initiation of new field projects. Studies of these existing facilities are self-limiting and must be supplemented by laboratory work on fundamental processes and by field demonstration of designs incorporating new concepts. The WQCB has seven in-house projects and ten extramural projects addressing many aspects of wastewater management incorporating land application in the overall management concept.

Future research objectives are focused on the short-term needs of the wastewater management complex, as well as the long-range goals of PL 92-500. Short-term needs are designated as those associated with improvements scheduled for adoption within five years, while the long-term needs are designated as those associated with the 1983 and 1985 goals of the Water Pollution Control Act of 1972. Short-term plans place emphasis on expanding our quantitative data base through investigation of current operations involving crop irrigation and infiltration systems. Complementary research will be conducted to develop innovative approaches for achieving secondary treatment or more advanced levels of treatment for implementation prior to 1978. Long-range plans provide more flexibility for evaluation of integrated systems directed to the achievement of non-polluting discharge of treated wastewaters. Plans for obtaining this goal incorporate more laboratory studies and field development studies directed to modifying existing practices, combining process units to achieve better reuse of wastewater constituents, and exploring new ideas for incorporating wastewater reuse into the production of food and fiber products.

THE CURRENT DATA BASE

One can conceive numerous approaches for utilizing land application in the management of wastewaters. The options available involve varying degrees of pretreatment, a long list of cropping practices, and several choices for release of the renovated wastewater. Only a few of the many options have practical significance for use within the current time schedule for improving wastewater management facilities. We in the WQCB have categorized those land application approaches having potential for immediate use into three groups. These groups are (1) crop irrigation which includes both field and forest cropping systems, (2) infiltration-percolation which includes all types of recharge systems, and (3) overland-flow which includes all systems with planned runoff. The current state of knowledge for each of these groupings is at radically different stages of development and choices for project implementation vary accordingly. One considering the implementation of a crop irrigation project in a water-short area could expect generally favorable response to implementation of a project, while one considering the same type of crop irrigation project in a cool and humid region could expect closer scrutiny from government and public sectors. One considering overland flow for treatment of municipal wastewaters could expect rejection of anything but a development project involving research. These differing responses reflect the confidence or lack of confidence in the current technical data base. Improvement of the data base and dissemination of information at workshops and symposia like this one is an effective tool for providing the most recent technical data to decision makers.

CROP IRRIGATION SYSTEMS

Crop irrigation has been practiced for many decades and there is a great volume of qualitative information substantiating the benefits of utilizing treated wastewaters for irrigation in water-short areas. Technical information sources such as the survey conducted by Sullivan, Cohn, and Baxter[1] and the state-of-the-art report by Pound and Crites[2] provide comprehensive information on past and current practices. Summary type sources like these and reports on specific projects such as the renovation project at Pennsylvania State University[3] can be combined with the information in previous symposia[4,5,6] to make several technical judgments about utilization of crop irrigation systems. Specific areas of interest include pretreatment, site characteristics, acceptable loading rates, methods of application, crop response, effects on soils, and effects on groundwater.

Technical information accumulated over the last 75 years shows the following regarding pretreatment before irrigation use. The most common pretreatment provided is that which has been commonly referred to as secondary treatment and is achieved with processes such as activated sludge, trickling filters, or oxidation ponds. Polishing ponds are frequently used following the activated sludge or trickling filter process. Chemical disinfection may or may not be included, depending upon the type of crop to be irrigated with the effluent. Irrigation of park areas, golf courses, and human food crops are examples of uses where it is more characteristic for the treatment train to include secondary treatment, retention in a polishing pond, and chemical disinfection prior to use for irrigation. Irrigation of forage and fiber crops is often practiced without chemical disinfection as the final step. Irrigation with primary effluents is still practiced to some degree where the crop to be irrigated is a forage or fiber crop. The practice of irrigating crops with primary effluents has declined substantially since the 1930's just as the practice of irrigating crops with raw settled sewage declined from 1900 to 1930 and has been virtually abandoned in the United States. Decline in the application of raw sewage to the land has paralleled the decline in discharge of raw sewage to surface waters. There is a good technical data base to link outbreaks of human illness with contamination of foods by raw or partially treated sewage via either land application or discharge to surface waters. Bryan[7] tabulated 73 outbreaks of human illness associated with sewage contamination of foods. He reports that foods grown in water were the vehicle in 42 cases (water discharge) and vegetables, fruits, or beef were the vehicle in 28 cases (land application). Technical information such as this provides a sound data base to support the trend toward secondary treatment prior to most irrigation uses.

Site characteristics for the hundreds of facilities currently in operation vary greatly. Numerous sources including those already cited and numerous others referred to in a recent publication of 570 abstracts[8] show that there are no hard and fast guidelines which describe the one best site. Site selection must be approached on a case-by-case basis with attention to the fundamentals of soil properties, the local hydrologic cycle, the local climate, and the overall objectives of the planned waste-water management system. Soil properties exhibited by medium-textured soils offer a compromise between the hydraulic limitations imposed by clay soils and the poorer contaminant removal of the hydraulically desirable sands. Frequently, the choice between available sites will depend heavily on the texture of the soil. The local hydrologic cycle is a key factor which has been overlooked all too often in the assessment of site characteristics. The remedial action required to correct the resultant water-logging of a site can be difficult and costly. Parsons[9] gives an account of system modifications which are quite typical. Pound and Crites,[2] page 186, recount a more complicated resolution of a water—logging problem. Experiences such as these demonstrate the results of overlooking the hydrologic cycle. It is a sound technical judgment to consider artifical means of drainage when a site assessment leaves doubt about the capability of the natural cycle to handle the added water load. Acceptable loading rates are site specific but can be expected to fall within the range of 2.5 to 10 cm per week (1 to 4 inches per week). By our definition of land application systems, we arbitrarily place application rates greater than 10 cm per week in the infiltration-percolation or overland-flow categories. The application rates must be selected to be compatible with the soil and climatic conditions. Clay soils in cool regions dictate lower rates, while sandy soils can accommodate higher rates in most localities. For example, the Muskegon wastewater management system, which is an underdrained system on sandy loams with a naturally occurring shallow water table, has a design load of 8.5 cm per week (3.4 inches per week). The hydraulic load is frequently the limiting factor for determining area requirements but there are other factors which are contributory and may be the limiting factor. Nitrogen bleed-through to the underlying groundwater may become an increasingly important factor in this respect. Nitrogen removal by crop irrigation systems is largely dependent on crop uptake and removal of the crop. In cases where nitrogen bleed-through (usually in the form of nitrate) is not acceptable, a nitrogen loading somewhat greater than that which can be removed in the harvested crop may limit the hydraulic loading.

The crop response to sewage irrigation has been well documented as to yield and some specific factors regarding composition. There is conclusive evidence that yields are comparable to those achieved with the use of fresh water for irrigation and commercially available mineral fertilizers. The generally observed increase in vegetative yield is not always a benefit because there are other factors which influence the value of a crop. For instance, sugar beets and sugar cane may yield more tonnage but less total sugar due to a reduction in sugar content. The choice of crop is largely a management and marketing decision which must be integrated into the overall project plan. It may be technically sound to select a crop and management option which results in average crop returns rather than high crop returns.

Use of treated wastewater for irrigation does have effects on the soils. These effects are site specific and are substantially different in arid and semi-humid regions. The technical data available indicates that secondary effluents have been used for many decades without noticeable effects on the soil when used at normal irrigation rates. The EPA[10] has issued criteria for the use of treated wastewaters as a source of irrigation water. Effluents meeting these criteria should not affect the properties of the soil sufficiently to reduce crop yields or cause severe management problems.

Crop irrigation systems contribute a fraction of the applied wastewater to underlying formations after passage through the soil. The fate of this fraction of the applied wastewater and its potential effect on the composition of existing groundwater is a complex issue. The nature of potential effects on groundwater is dependent on many factors related to the quality of the waste treatment plant effluent, concentration changes induced by climatic influences, quality changes effected by the plant-soil community, and the occurrence and quality of existing groundwater. There are several prime factors to consider in the technical assessment of a project in the planning process. Climatic conditions in the east favor the situation where existing groundwater will be of substantially better quality than the applied wastewater in most situations. Present technical information presents a sketchy data base because the practice of crop irrigation with treated wastewaters is not prevalent in the east. Data available for systems which have seen long service in semi-arid regions is not a sound technical base for use in the east because the concentration changes induced by climatic influences are radically different. Those projects which include recovery of the renovated wastewater or delineate a monitored zone of groundwater influence show the best conformity with existing technical knowledge.

INFILTRATION-PERCOLATION

Like crop irrigation, the use of various infiltration-percolation concepts including recharge basins, ridge and furrow systems, and spray disposal systems has been practiced for many decades. Unlike crop irrigation, these systems have been utilized primarily for "waste disposal" or more appropriately as one process unit in a "waste treatment" system. This approach has been practiced extensively for management of municipal wastewaters and industrial wastewaters. Our discussion of this topic will be limited to the use of infiltration-percolation systems as an advanced waste treatment approach for municipal effluents. Pertinent information sources are limited primarily to project reports for specific facilities such as those at Santee, California,[11] Phoenix, Arizona,[12] Detroit Lakes, Minnesota,[13] and Lake George, New York.[14] Pound and Crites[2] assess current technical information as well as provide details on several active systems. Several agencies are collecting information on other systems at the present time and the technical data base is expanding rapidly. Consequently, technical judgments made today are subject to revision or refinement in the near future. Specific areas of interest include pretreatment, site characteristics, acceptable loading rates, the role of crops, treatment achieved, and effects on groundwater.

The use of infiltration-percolation systems in the management of municipal wastewaters has been directed to the polishing of primary or secondary effluents prior to their discharge into receiving waters. The majority of these facilities provide secondary treatment prior to use of infiltration-percolation for advanced treatment. Assessment of operations at existing facilities indicates that advantages attributed to providing secondary treatment include much greater acceptable loading rates, better control of nuisance vectors, and less trouble with soil clogging. The available technical data support the contention that these advantages justify the cost of providing classical secondary treatment. There is ample technical data to substantiate the effectiveness of intermittent soil filtration as an effective means for achieving fecal coliform reduction equivalent to that of chemical disinfection, therefore, chemical disinfection as a routine pretreatment practice is technically questionable in many situations.

Site characteristics favorable for the use of infiltration-percolation differ substantially from those most suited to crop irrigation. The most favorable sites are easier to define because soil properties, the local hydrologic cycle, and project objectives place more constraints on the site characteristics. The best suited sites would have three meters or more of an unsaturated sandy soil overlying an impervious barrier or a water table with restricted vertical permeability. The restriction to vertical permeability would permit ready recovery of the renovated water or promote lateral movement through the permeable formation to a nearby surface discharge as a seep or spring. A good example of a favorable site in a cool, humid climate is the Lake George, New York facility.[14] There is a good technical data base for projecting the performance of infiltration-percolation systems and those sites which provide for containment or recovery of the renovated water can be readily assessed with available data. Sites which do not have favorable characteristics must be considered on a case-by-case basis and require more site evaluation work. The evaluation of the site should provide data to assure the attainment of a desired level of advanced treatment without waterlogging the site or causing unacceptable quality changes in an existing groundwater body.

The concept of the infiltration-percolation system is directed to relatively high loading rates. Acceptable rates vary greatly because they are site specific but they range from about 10 meters to 100 meters per year. The available technical data base has not been sufficiently developed to provide a ready reference for selecting loading rates. Some on-site testing of infiltration rates and transmissibility are needed to assure selection of an acceptable long-term loading rate. This on-site testing should determine that aerobic conditions can be maintained at the proposed loading rate and that the natural hydrologic cycle or an artificially induced subcycle will maintain a minimum unsaturated depth of more than one meter. Soil systems operating at these high loading rates do not have the capability to remove many inorganic constituents as effectively as the crop irrigation systems. Removal of nitrogen is of specific interest in this instance since areal loadings are high and much of the applied nitrogen appears in the renovated water in the nitrate form. The control of denitrification in the soil environment offers a practical mechanism for obtaining nitrogen removal by converting the nitrogen forms found in the wastewater effluent to nitrogen gas. Research is under way to develop reliable technology for effective use of the denitrification process.

The role of crops in the effectiveness of infiltration-percolation systems is of minor consequence. Nutrient loadings greatly exceed plant uptake rates and the influence of crop removal is a minor factor in the mass removal of potential contaminants. Some evidence is available which shows that cover crops are effective in the maintenance of the infiltration rates, however, there is divided opinion on this benefit and many infiltration-percolation systems are operated without any vegetative cover. The technical data base currently available indicates cover crops are not necessary for successful operation of infiltration-percolation systems for advanced treatment of municipal treatment plant effluents.

The treatment achieved by infiltration-percolation systems has been well established for many contaminants remaining in secondary effluents. Contaminants which are essentially eliminated by the infiltration-percolation process include suspended solids, biochemical oxygen demand, fecal coliforms, and certain viruses. Phosphorus can also be reduced to very low levels, typically less than 0.5 mg/1, with appropriate travel distances of several hundreds of meters and retention times of several weeks. Other contaminants including pesticides, heavy metals, and selected inorganic species are substantially reduced but the degree of removal for individual species has not been established through the accumulation of a reliable data base. Like phosphorus, the removal of many of these species is a function of residence time and travel distance involving physical, biochemical, and chemical interactions of considerable complexity. Readily soluble ionic species including sodium, chloride, nitrate, and sulfate are not appreciably reduced by infiltration-percolation systems and can be expected to remain in the renovated water after long distances of travel and long residence times. Interest in many potential contaminants such as heavy metals and pesticides has developed recently and the historical data base on the treatment efficiency of infiltration-percolation contains little quantitative data for these contaminants. The historical data base does contain much reliable data on the excellent removal achieved for suspended solids, biochemical oxygen demand, fecal coliform, certain viruses, and phosphorus. Comprehensive study of on-going facilities will provide quantitative data to fill gaps in the current technical data base.

Infiltration-percolation system designs incorporate underground storage of the renovated wastewater, therefore, the effects of these systems on the quality of existing groundwater is a fundamental factor to consider in the planning stage. Infiltration-percolation systems do, as already discussed, achieve excellent removal of many of the residual contaminants in secondary effluents. These removals do not assure a water with a quality equal to that of existing groundwaters. In special situations the quality of the renovated wastewater may be better than that of the existing groundwater and recovery of the renovated water before it merges with existing groundwater may be desirable. This would not be a common occurrence, particularly in the eastern United States, and technical evaluation of a proposed infiltration-percolation system will usually be directed to maintenance of desired groundwater quality by selection of specific management techniques. One positive technique is containment and recovery of the renovated wastewater for reuse or direct surface discharge. A second positive technique is the selection of a site which assures discharge to a surface water through a naturally occurring underground flow terminating in a nearby surface seep. The flow path to the surface seep should not be subject to use for water supply wells without appropriate monitoring practices. A third technique for management of infiltration-percolation effects on groundwater quality is that of artificially inducing dilution or utilizing naturally occurring dilution in the groundwater body to maintain desired groundwater quality.

The technological base for adoption of any one of these three management techniques varies in reliability. Obviously, the containment and recovery technique offers the easiest case for substantiation and there is a good data base available. Underground flow to a natural surface seep is more difficult to substantiate but there are several existing systems which are being or can be studied to improve the reliability of the technical data base. The underground dilution technique requires extensive on-site evaluations to determine the relative quality of the secondary effluent to be applied, the renovation achieved by infiltration-percolation, the quality of the existing groundwater, the amount and quality of natural or other man-provided dilution waters, and the final quality of the blended water. Development of a reliable technology base for this underground dilution technique will require detailed evaluations at many demonstration-type facilities.

OVERLAND FLOW

Overland-flow treatment of municipal wastewaters is an essentially new concept for implementation in the United States. Successful management of food processing wastewaters by this technique,[15] some data from a few facilities in England[16] and Australia,[17] and progress reports for two on-going research efforts in the United States[18,19] are the principal sources for the current technical data bank. The information available indicates this approach has potential as an alternate approach for treatment of raw wastewater or as a technique for upgrading primary and secondary effluents from conventional treatment plants. The overland-flow approach is a treatment approach which is suited to sites with very low infiltrative capacity. The basic concept of the approach is to use the surface soil and the associated plant and animal life as an integrated biochemical and chemical treatment process. Wastewater is applied to a smoothed and sloping area covered with grass. The applied wastewater moves downslope by sheet flow to a point where it is intercepted by a terrace ditch for discharge to a surface water. Development of a data base for treatment of municipal wastewater by this approach is just beginning to emerge. Information pertaining to site characteristics, management concepts, the role of crops, and effects on the surroundings can be deduced from experiences with other wastewaters. Specific data on pretreatment effects, acceptable loading rates, and treatment efficiency must be developed through laboratory and field testing programs. Overland flow is being covered in this discussion of practical land application approaches because it has great technical potential for providing advanced treatment of raw municipal wastewater at a cost comparable to the cost of primary treatment. It accomplishes this treatment with the added benefit of eliminating the production and subsequent handling of sludges.

The technical feasibility of employing overland flow to treat raw municipal wastewater has been demonstrated by three years of study at RSKERL. The results of this research effort show that an average load of 10 cm/week can be applied in climates comparable to that of south central Oklahoma. The effluent from the overland flow area would be substantially better than required to meet the current EPA definition of secondary treatment with respect to suspended solids and biochemical oxygen demand. The pH would be in the specified range and disinfection to meet the coliform criteria would require comparatively low doses of disinfectant due to lack of interfering constituents. Removal of about 85 percent of the total nitrogen and about 60 percent of the total phosphorus are added benefits of normal management. A study to assess system performance while treating a 380 m^3 per day flow (0.1 mgd) will start operation in the spring of 1975 at a south central Oklahoma community.

Overland flow or grass filtration following primary or secondary treatment is currently practiced in Australia and England. Treatment of raw settled sewage has been practiced seasonally at Melbourne, Australia[17] for several decades. The objective of this practice is to provide acceptable wastewater treatment in the cool and rainy winter period when crop irrigation is not being practiced in the pasture area. Kirby[17] reports removals of 95 percent for suspended solids, 96 percent for biochemical oxygen demand, 60 percent for nitrogen, and 35 percent for phosphorus with continuous application at a rate of 14 cm per week for the grass filtration area. Walker[16] reports on the effectiveness and cost of grass filtration as a method of polishing secondary effluents in England. He reports on costs, rates of application, and the improvement in treatment efficiency at four installations. About 60 percent of the suspended solids and biochemical oxygen demand in the secondary effluents were removed by grass filtration at loading rates of .06 to 0.25 m^3/m^2 per day (.05 to 0.22 mgd/acre). Studies under way by Hoeppel, et al.[18] will advance our knowledge of the overland-flow process and may act as the seed for growth of a technological base to establish overland flow as a technique for polishing secondary effluents in the United States.

EPA RESEARCH

We have touched on EPA research efforts in the discussion of current land treatment options. Now, let us address some completed or ongoing studies in more detail as well as projecting our plans for filling the gaps in the technological data base. Detailed discussion of the results of completed or ongoing studies will be directed to clarification of technical judgments regarding the present technical data base. Discussion of future plans will provide insight into the type of additional information being sought and an estimate of when various bits of information will become available.

COMPLETED AND ONGOING STUDIES

In keeping with the arrangement of the discussion of current options, this discussion will address crop irrigation, infiltration-percolation, and overland-flow projects separately. An additional category of basic research applicable to more than one category will close the section.

Crop Irrigation

Cropland irrigation with municipal effluents is a well-established practice in the southwestern United States. Many facilities have practiced effluent irrigation for more than 30 years at the same site. Utilization of the practice has grown steadily since the first operations were initiated in the late 1800's and some 300 facilities are active at present. In spite of this impressive number of active facilities, there is an obvious lack of quantitative data to delineate the balance between the beneficial and adverse influences on the local environment. Our laboratory has completed or is actively involved in ten field projects addressing various aspects of crop irrigation practices.

One group of projects places emphasis on locating and evaluating currently available quantitative information on application rates, crop responses, soil changes, and groundwater quality changes. To date, this approach has been very useful in defining management techniques for general use in the Southwest, as well as furnishing a base for other geographic locations. A recently completed survey of existing facilities[1] and an assessment of current technology[2] summarize the accomplishments.

A second group of projects is designed to demonstrate crop irrigation approaches in geographic areas where historical information is scarce. The long-term project at Pennsylvania State University[3] is an example of a project of specific regional significance. The ten years of data collection at this site shows that crop irrigation can benefit crop production in a cool, humid climate with little effect on the local groundwater body. Other ongoing demonstration projects of specific interest include the Muskegon Wastewater Management System; a smaller study at Belding, Michigan; a study at Falmouth, Massachusetts; and a study at Tallahassee, Florida. The Muskegon project is designed to demonstrate seasonal irrigation in conjunction with off-season storage of all treated wastewater, as well as complete recovery of the renovated wastewater for surface discharge. This total containment system represents a very advanced concept of crop irrigation for wastewater management. The 1975 season will be the first for collection of full season data for all system components. Data collected over the next several years will be an important addition to the current data base. The study at Belding, Michigan utilizes an oxidation pond effluent (a 5-cell pond system) in a summer irrigation program for forages, sod, and ornamentals, and in a winter irrigation program for forages. This study is providing additional data on winter operations, responses of sod and ornamentals, and water quality influences resulting from non-containment operations. The site has sandy soils over a shallow water table which promotes lateral movement through interflow with discharge to a surface stream. The Falmouth, Massachusetts study is designed to demonstrate several management techniques on sandy soils with recharge of the groundwater in a sand aquifer at a depth of about ten meters. The Tallahassee, Florida study has a similar objective for a project site with radically differing climatic conditions. Interpretative data from these projects will become available within a year or two.

Infiltration-Percolation

Infiltration-percolation is a well-established practice at many small municipal facilities throughout the United States. Design and operation of these systems have emphasized the safe disposal of a treatment plant effluent, and it is only within the last decade that an effort has been made to determine the treatment which can be achieved by adjusting the management of a system. Our laboratory has been or is actively involved in nine field studies addressing the evaluation and demonstration of management options which enhance the treatment achieved by infiltration-percolation systems.

Previously completed studies include four research studies in water-short southwestern states and two research studies in water-rich north central states. The studies in the southwest were conducted at Whittier Narrows, California,[19] Santee, California,[11] Phoenix, Arizona,[12] and Hemet, California.[20] The studies in the north central area were in Detroit Lakes, Minnesota,[13] and Westby, Wisconsin.[21] The study at Whittier Narrows, California was conducted to study the effectiveness of the infiltration-approach for direct recharge of a potable groundwater supply with secondary effluent.[19] The results of this study showed that spreading periods of about 9 hours followed by drying periods of about 15 hours produced a clear and highly oxidized water acceptable for recharge at this site. This method of operation resulted in conversion of almost all applied nitrogen to nitrate and produced nitrate concentrations in the renovated water two to three times more than acceptable limits for drinking water. Due to the high nitrate concentration, it was recommended that dilution with low nitrate water would be necessary before repumping for use as a water supply. The concurrent study at Santee, California evaluated the use of infiltration-percolation to make municipal effluent suitable to fill and maintain the water level in recreational lakes.[11] Locating the infiltration-percolation basins in the alluvium of a shallow stream channel provided substantial lateral movement underground after about 3 meters of vertical percolation. In addition to excellent removal of solids, oxygen-demanding substances, pathogens, and phosphorus, total nitrogen in the renovated water was reduced to 1.5 mg/1 (from 25 mg/1 applied to spreading basins) after about 500 meters of lateral underground travel. Emphasis was placed on evaluating this nitrogen removal at the Phoenix, Arizona study using a similar mode of operation.[12] Results of the Phoenix study showed that the frequency of application has a major influence on nitrogen removal. Spreading and drying periods of a few days or less promoted nitrification and resulted in less than 10 percent total nitrogen removal, whereas spreading and drying periods of 10 to 20 days resulted in apparent denitrification and up to 80 percent nitrogen removal. This study also highlighted the importance of underground residence time and/or distance of travel for achieving phosphorus removal at the high loadings used for the infiltration-percolation approach.

Another important factor related to local hydrological conditions was graphically demonstrated by the study at Hemet, California.[20] An unusually wet winter season at this location caused the local water table to rise up to the bottom of the spreading basins. The resultant reduction in hydraulic acceptance rate and deterioration of treatment efficiency made it necessary to quickly develop an alternate method for handling their effluent.

Although the two north central area studies represent radically differing climatic conditions, overall performance was quite similar to that observed in the southwest. The Detroit Lakes, Minnesota project entailed a four-year experiment using 20-hour spraying periods followed by 4-hour drying periods to apply about 30 meters per year of effluent on a sandy soil.[13] Our definitions place this system in the infiltration-percolation category even though it uses spray application and is referred to as a spray irrigation system. It is significant that the use of short spreading and drying cycles in this climate produced nitrogen and phosphorus interactions comparable to those for studies in the southwest. Nitrogen was converted to nitrate which appeared in the groundwater (at a concentration comparable to that in a municipal effluent) while 70 percent of the phosphorus was removed after no more than 7 meters of travel distance through the soil. The other study in this climate was a one-year evaluation of the performance of an existing ridge and furrow basin facility.[21] The system was located on a silt loam soil and a loading of about 15 meters per year was obtained with wetting periods of two weeks followed by drying periods of two weeks. As was the case for the study in Arizona, the long spreading period resulted in about 70 percent removal of total nitrogen without affecting the removal capacity for other measured parameters.

The first of several studies to make comprehensive evaluations of existing infiltration-percolation facilities has just been initiated at Lake George, New York. Several studies of this type will be implemented to expand the scope of quantitative data to include parameters of current interest. Completed and ongoing research on the infiltration-percolation approach to land spreading of municipal effluents are encouraging for future use on a much larger scale. Technological data are already available to design and operate systems for a limited number of situations, but of more importance is the apparent utility of the approach under widely differing climatic conditions. We are optimistic that further research efforts can establish well-defined design criteria and management techniques for use throughout the United States.

Overland Flow

Overland-flow treatment of municipal wastewaters is a newly developing technology in the United States. Our laboratory has completed an 18-month study to assess the technical feasibility of treating raw sewage by overland flow.[15] The positive results of this study, as well as a just completed 15-month extension of the study to explore alum addition for improving phosphorus removal have led to two new studies. One of these is a field evaluation to study overland flow for a 380 m^3 daily flow (0.1 mgd) at a small rural city. The second is a test to compare treatment efficiency and area requirements for primary and secondary effluents as opposed to direct treatment of raw sewage. These efforts are a small fraction of the total effort which will be required to establish overland flow as a viable alternative to other established wastewater management approaches.

Basic Research

In addition to studies addressing specific land application approaches, our laboratory is conducting or has supported several studies on fundamental processes which are involved in the functioning of land application systems. Studies have been focused on special aspects of phosphorus retention in soils, denitrification, biodegradation of organics, and climatology.

Phosphorus retention in soil has been studied from the specific aspect of predicting long-term phosphorus removals by measurement of specified soil properties. Enfield[22] has reported an initial prediction model based on laboratory work with 26 mineral soils. Completed and ongoing denitrification studies are addressing the relation of oxygen status in an attempt to delineate management approaches for achieving and maintaining 90 percent nitrogen removal by denitrification. Continuing studies on biodegradation of organics have addressed the use of ATP (adenosine triphosphate) as a tool to measure bioactivity and the use of small-scale laboratory apparatus to assess the relative biodegradability of wastewaters from different sources. The study of climatology has been directed to assessing the value of readily available weather data for determining winter storage needs. These basic studies have applicability to all three land application approaches and provide a better basis for establishing field projects to develop or demonstrate specific features of improved technology.

FUTURE RESEARCH

Future plans for research on land application approaches adhere to our categorization of land application into three specific types of systems. The short-range plans call for utilization of studies on existing systems and selected demonstration projects to gain as much improvement in the data base as is possible in a short time. These short-range plans address the 1977 and to some degree the 1983 milestone dates of PL 92-500. The long-range plans call for directing more attention to the study of innovative combinations of land application alone or with other process units to achieve a very high degree of contaminant control. These long-range plans address the 1985 goal of nonpolluting discharge, as well as the intermediate 1983 goal of best practicable waste treatment technology.

SHORT-RANGE PLANS

Projected Branch support over the next two to three years will provide a diversified program which will make important gains in all four of the major research areas. Emphasis will be placed on filling technology gaps for the crop irrigation and infiltration-percolation approaches which are being implemented as alternative wastewater management systems at the present time. Development of overland-flow technology will be aimed at assisting small rural communities needing a simple and economical secondary process. Basic research will continue with little change in goals or emphasis.

A major fraction of short-term support will be allocated to collection of quantitative data at about ten existing crop irrigation systems and ten existing infiltration-percolation systems. These one- to two-year studies should be completed by the end of FY 1977 and the results of the studies will be distributed as technical information bulletins shortly thereafter. The short-range plans also call for initiation of several demonstration projects in anticipation of a need to demonstrate improved management techniques for the crop irrigation and infiltration-percolation systems. Efforts will be made to select project sites in geographical locales where governmental units and the public are interested in the potential of land application but do not have ready access to observe an ongoing facility. These short-term efforts on the crop irrigation and infiltration approaches will emphasize the collection of quantitative data to delineate the cans and cannots of existing design technology. Major efforts to develop new design technology will be considered as a long-range objective.

The short-term plans for overland-flow studies also address the development of new technology as do the basic research studies. Short-term objectives for overland-flow studies will emphasize two areas of development. One of these will be the development of overland flow as a unit process for treatment of raw municipal wastewaters on a year-round basis in southern states. Overland flow will offer many rural communities a much needed method for meeting or exceeding the present definition of secondary treatment at a cost comparable to that of primary treatment.

The second objective will be the development of overland flow as a seasonal operation for upgrading existing pond systems which cannot meet present criteria for secondary treatment. The prospects for developing a timely data base for these two objectives are good and there is an obvious need for the intended results. Basic research will continue in the areas already under study, as well as being expanded to include work on heavy metals. Short-term goals include positive identification of denitrification as the mechanism for nitrogen removal by overland flow; establishment of a method for predicting soil removal of phosphorus; a routine methodology for predicting winter storage needs from weather station data; and development of the ATP procedure for measuring bioactivity in soils. Completion of work in other areas will fall under long-range plans.

LONG-RANGE PLANS

Projected Branch support from FY 1977 through FY 1981 should support a program which will culminate in the distribution of technical bulletins on crop irrigation, infiltration-percolation, and overland flow. These technical bulletins will detail procedures for planning a land-based wastewater management system, selecting the process train best suited to the site, designing the system, and operating the system. These technical bulletins will be complemented by a series of research reports providing reliable technical data which substantiate the recommendations contained in the bulletins. Much of the data in the research reports will have come from demonstration projects which will still be in operation as permanent facilities. Establishment of demonstration projects at sites where operations will continue for several decades is a key objective in long-range plans. The value of these sites for visual inspection and periodic collection of quantitative data is an essential building block for establishing a reliable data base which can be extended beyond the immediate needs for revamping our wastewater management methodology.

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Land Application Practices and Design Criteria

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INTRODUCTION

Land application of wastewater or treated effluent involves the use of the soil surface and soil matrix for renovation. Renovated water may discharge to groundwaters or may be collected for surface water discharge. Because land application involves physical, chemical, and biological treatment, the renovated water is generally comparable in quality to effluents from advanced wastewater treatment processes.

The practice of land application is nationwide; however the majority of the existing systems are found in the west and southwest. As water quality requirements become more stringent, alternatives that involve land application will require increased consideration. In this paper, the engineering aspects of land application systems will be discussed for the major techniques and a case study involving a preliminary design will be presented.

LAND APPLICATION METHODS

Systems involving land application of municipal effluents are normally categorized into three types of systems based on differences in liquid loading rates, land area requirements, and the interaction of the wastewater with vegetation and soil. These three categories are referred to as (1) irrigation, (2) infiltration-percolation, and (3) overland flow. Selection of the method or combination of methods at a given site is primarily governed by the drainability of the soil, because it is this property that largely determines the allowable liquid loading rate. Schematic diagrams indicating the major process characteristics of each of the systems are shown in Figure 1. A summary of the comparative characteristics of the three systems is presented in Table 1[1].

Irrigation

Irrigation involves applying effluent to the land, by spraying or surface spreading, to support plant growth and treat the effluent. This method is the most popular of land application techniques and is generally the most reliable. Feed, fiber, and food crops can be grown, provided the effluent is adequately treated to meet public health standards. Forestland, parks, and golf courses can also be irrigated.

Site Characteristics — The range of suitable site characteristics for irrigation systems is wide. The major criteria are as follows:

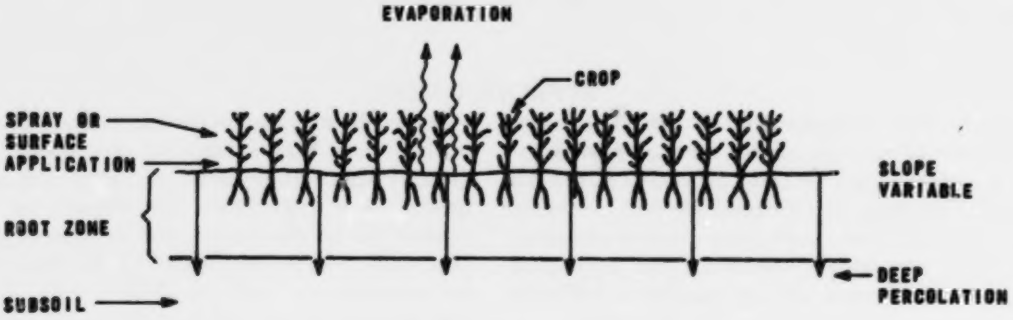
- Climate — Warm-to-arid climates are preferable but more severe climates are acceptable if adequate storage is provided for wet or freezing conditions.
- Topography — Slopes up to 15 percent for crop irrigation are acceptable provided runoff or erosion is controlled.
- Soil type — Loamy soils are preferable, but most soils from sandy loams to clay loams are suitable.
- Soil drainage — Well-drained soil is preferable; however, more poorly drained soils may be suitable if drainage features are included in the design.
- Soil depth — Uniformly 5 to 6 feet or more throughout sites is preferred for root development and wastewater renovation.
- Geologic formations — Lack of major discontinuities that provide short circuits to the groundwater is necessary.
- Groundwater — A minimum depth of 5 feet to groundwater is normally necessary to maintain aerobic conditions, provide necessary renovation, and prevent surface waterlogging. Control may be obtained by underdrains or groundwater pumping.

Irrigation Techniques — Three application techniques are employed in irrigation systems (Figure 2):

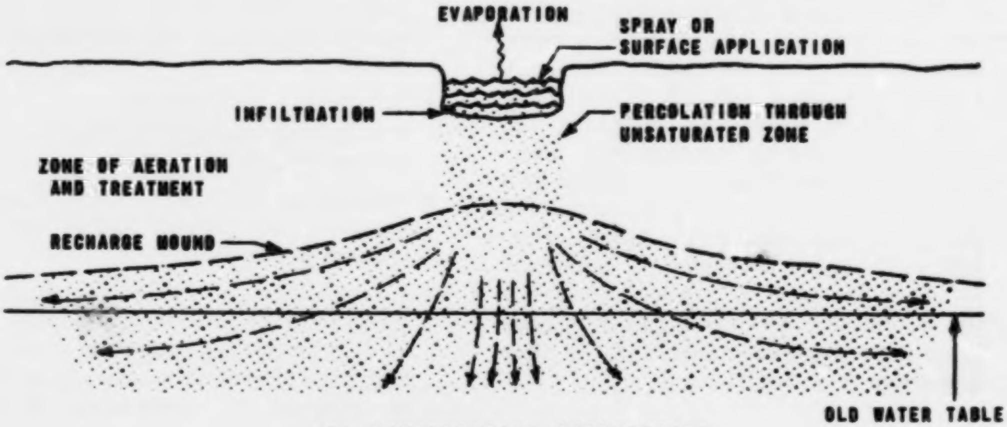
- Spraying
- Ridge and furrow
- Flooding

Topography, soil conditions, weather conditions, agricultural practice, and economics are factors to be considered in technique selection.

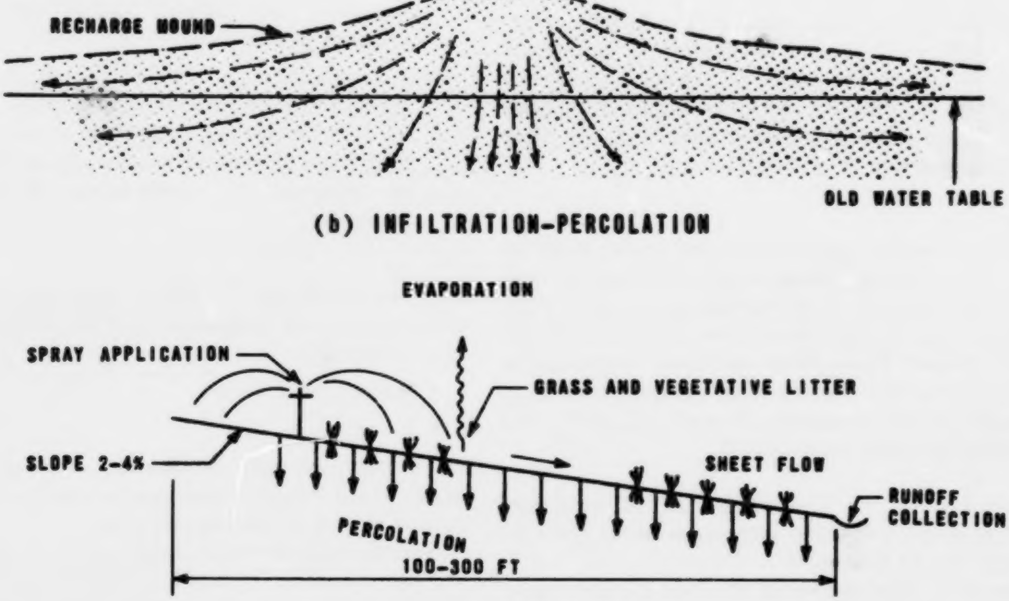
Spraying involves the application of effluent above the ground either through nozzles or sprinkler heads. Other elements of the system include: pumps or a source of pressure, supply mains, laterals, and risers. Design of a system can be quite variable; it can be portable or permanent, moving or stationary. Spray systems are the most efficient for uniform flow distribution, but such systems are also generally the most expensive. High wind, a problem common to spray irrigation systems, adversely affects efficiency of distribution and can also spread aerosol mists. Hydraulic


EVAPORATION
CROP
SPRAY OR SURFACE APPLICATION
SLOPE VARIABLE
ROOT ZONE
DEEP PERCOLATION
SUBSOIL

(a) IRRIGATION


EVAPORATION
SPRAY OR SURFACE APPLICATION
INFILTRATION
PERCOLATION THROUGH UNSATURATED ZONE
ZONE OF AERATION AND TREATMENT
RECHARGE MOUND
OLD WATER TABLE

(b) INFILTRATION-PERCOLATION


EVAPORATION
SPRAY APPLICATION
GRASS AND VEGETATIVE LITTER
SLOPE 2-4%
SHEET FLOW
RUNOFF COLLECTION
PERCOLATION
100-300 FT

(c) OVERLAND FLOW

FIGURE 1. METHODS OF LAND APPLICATION

Table 1. COMPARATIVE CHARACTERISTICS OF IRRIGATION, INFILTRATION-PERCOLATION, AND OVERLAND FLOW SYSTEMS

Factor	Irrigation		Infiltration-percolation	Overland flow
	Low-rate	High-rate		
Liquid loading rate, in./wk	0.5 to 1.5	1.5 to 4.0	4 to 120	2 to 5.5
Annual application, ft/yr	2 to 4	4 to 18	18 to 500	8 to 24
Land required for 1-mgd flowrate, acres[a]	280 to 560	62 to 560	2 to 62	46 to 140
Application techniques	Spray or surface		Usually surface	Usually spray
Crop production	Excellent	Fair	Poor	Fair
Soils	Moderately permeable soils with good productivity when irrigated		Rapidly permeable soils, such as sands, loamy sands, and sandy loams	Slowly permeable soils, such as clay loams and clays
Climatic constraints	Growing season only	Storage often needed	Reduce loadings in freezing weather	Storage often needed
Wastewater lost to:	Evaporation and percolation		Percolation	Surface runoff and evaporation with some percolation
Expected treatment performance				
BOD and SS removal	98+%		85 to 99%	92+%
Nitrogen removal	85+%[a]		0 to 50%	70 to 90%
Phosphorus removal	80 to 99%		60 to 95%	40 to 80%

a. Dependent on crop uptake.

Metric conversion: in. x 2.54 = cm
ft x 0.305 = m
acre x 0.405 = ha

design factors for spraying systems are included in references [2,3,4]

Ridge and furrow irrigation is accomplished by gravity flow of effluent through furrows, from which it seeps into the ground. Utilization of this technique is generally restricted to relatively flat land, and extensive preparation of the ground is required. The operating cost is relatively low, and the technique is well suited to certain row crops. Uniformity of distribution, however, is difficult to maintain unless slope irregularities are eliminated.

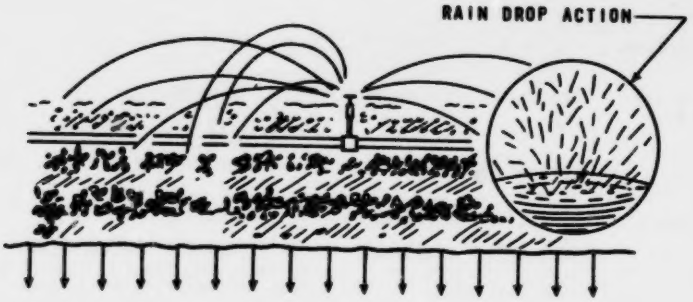
Irrigation by flooding is accomplished by inundation of the land with several inches of effluent. Descriptions of the various flooding techniques are contained in *Wastewater Treatment and Reuse by Land Application* [5]. The depth of applied effluent and period of flooding are dependent on the characteristics of the soil and the crop grown. The technique is well suited to irrigation of grasslands.

Infiltration-Percolation

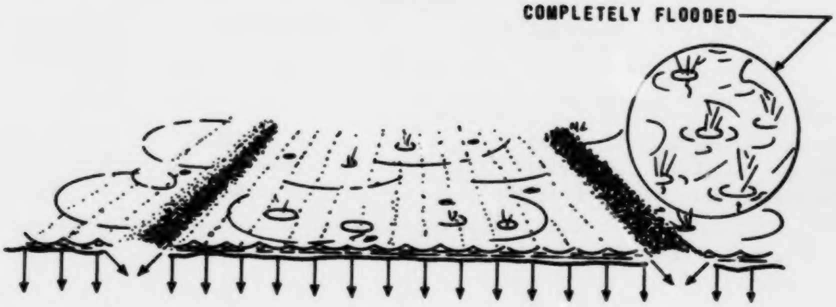
In this method, effluent is applied to the soil by spreading in basins or by spraying, and is treated as it travels through the soil matrix. Vegetation is generally not employed although there are some exceptions. Preapplication treatment is generally provided to reduce the suspended solids content and thereby allow the continuation of high application rates. Secondary treatment is often provided prior to spreading or ponding although primary treatment effluent has also been used.

Site Characteristics — Because most of the applied effluent percolates through the soil, soil drainage is usually the limiting site characteristic. Other site evaluation criteria include:

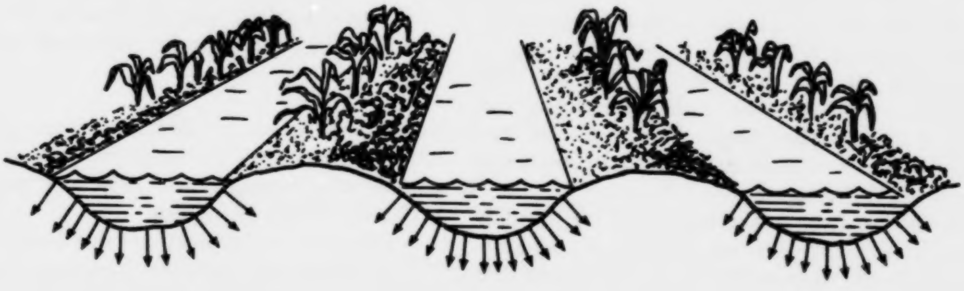
- Climate — Infiltration-percolation is applicable to nearly all climates. Loadings may need to be reduced for cold weather conditions.
- Topography — Level terrain is preferable, but rolling terrain is acceptable.
- Soil type — Acceptable soils include sand, sandy loams, loamy sands, and gravels. Soils that are too coarse provide insufficient renovation.
- Soil drainage — Moderate-to-rapid drainage is preferable.
- Soil depth — Uniformly 10 to 15 feet of soil depth is preferred.


RAIN DROP ACTION

(a) SPRINKLER


COMPLETELY FLOODED

(b) FLOODING



(c) RIDGE AND FURROW

FIGURE 2. BASIC METHODS OF APPLICATION

- Geologic formations — Lack of significant discontinuities is necessary.
- Groundwater — A minimum depth of 15 feet to the existing water table is necessary; it should not be allowed to rise to less than 4 feet from the ground surface. Control by underdrains may be required.

Infiltration-Percolation Techniques — Spreading and spraying are two application techniques suitable for infiltration-percolation. Spreading using basins is the most common technique. Spreading can usually be continued through freezing weather if underground piping is used. Multiple basins are generally used and periods of flooding are alternated with periods of drying.

Application by spraying is less common to municipal systems being found mostly in industrial systems. Normally, vegetation such as hydrophytic grasses is used to protect the soil surface from the impact of the spray droplets and maintain the high infiltration rates.

Overland Flow

In this method, wastewater is sprayed over the upper reaches of sloped terraces and allowed to flow across the vegetated surface to runoff collection ditches. Renovation is accomplished by physical, chemical, and biological means as the wastewater flows in a sheet through the vegetation and litter. Preapplication treatment should include removal of large solids, grit, and grease that hamper effective spraying. The renovation noted in Table 1 has been shown for domestic as well as industrial wastewaters. For domestic wastewater that is not adequately disinfected prior to overland flow treatment, disinfection of the collected runoff may be necessary.

Site Characteristics — Important site characteristics include:

- Climate — Warm climates are preferable, but more severe climates are acceptable if adequate storage is provided for freezing conditions.
- Topography — Rolling terrain is well suited; level terrain can be graded to create uniform slopes of 2 to 6 percent.
- Soil type — Clays and clay loams are preferable.
- Soil drainage — Poor or slow drainage is preferable.
- Soil depth — Six to 8 inches of good topsoil is needed.
- Geologic formations — Lack of major discontinuities is necessary.
- Groundwater — Groundwater should not interfere with plant growth.

Overland Flow Techniques — Spraying is the common application technique for overland flow using fixed sprinklers or rotating boom-type sprays. Application by flooding or other surface techniques in overland flow systems has not been demonstrated in this country, but it has been practiced successfully in Melbourne, Australia. If high concentrations of suspended solids are present, settling in the upper reaches may cause an odor problem. Because uniform distribution is critical, flooding may not be successful unless care is taken to produce an extremely smooth terrace with no noticeable depressions.

Combinations of Methods

Combinations of land application techniques may be desirable when dealing with problems of differences in site characteristics (either within one large site or between a number of sites), seasonal weather variations, or limiting water quality criteria. They may also be useful in adapting land application to present land use; for instance, using a portion of the wastewater to irrigate an existing golf course. The selection of the type of system or combination of systems to be designed should result from a thorough analysis of the treatment objectives, site and wastewater characteristics, and the available land application technology.

ENGINEERING DESIGN CRITERIA

Factors that affect the engineering design of land application systems include (1) climatic conditions, (2) wastewater quality, (3) crops or vegetation, and (4) the hardware involved in applying the wastewater. These factors affect each of the three basic treatment methods differently. For example, climatic conditions are more critical for irrigation than for infiltration-percolation. Consequently in a thorough discussion of these factors, which is not possible here, each type of system should be addressed separately.

Climatic Factors

Local climatic conditions will affect decisions as to the method of application, storage requirements, and acceptable loading rates. Important climatic factors include precipitation amounts and intensities, temperature, evapotranspiration, and wind.

Precipitation — The annual quantity and seasonal distribution of precipitation is important to the design of distribution and storage systems. Periods of intense precipitation or snow cover may prevent effluent application and require storage. Wetter-than-normal years should be used in the analysis of the storage requirements and in the conduct of the water balance.

Temperature — An analysis of temperature variations is useful in selecting the type of land application method and in estimating periods of nonoperation. Maximum periods of freezing and number of days where the high temperature remains below a certain value, say 25 degrees F for example, are important in design.

Evapotranspiration — Along with percolation and runoff, evapotranspiration represents a major part of the water loss portion of the water balance. Where evapotranspiration rates exceed precipitation, as they often do west of the Mississippi, the concentrating effect on the dissolved solids in the effluent applied should be considered. Temperature, wind, and relative humidity also influence evaporation rates.

Wind — Wind directioin and velocity are important in the design of sprinkling systems. High winds can cause uneven distribution of spray patterns. Systems designed for overlap during winds of 10 mph should have laterals spaced at 50 percent of the spray diameter[3].

Wastewater Quality

Important wastewater characteristics include constituents listed in discharge requirements, as well as constituents that can affect the efficiency of system operation. The importance and acceptable loadings of organic matter and inorganic constituents will be discussed.

Organic Matter — Organic matter includes BOD and COD as well as persistent, trace organics. The soil is a highly efficient biological treatment system; therefore, liquid loading rates at land treatment operations are normally governed by the hydraulic capacity of the soil rather than the organic loading rate. This operational independence from BOD loading is a distinct advantage of land treatment systems over conventional in-plant systems in treating high-strength wastewaters, particularly industrial wastes. There are limits, of course, to the organic loading that can be placed on the land without stressing the ecosystem in the soil. The effects of organic overloads on the soil include damage to or killing of vegetation, severe clogging of the soil surface, and leaching of undegraded organic material into the groundwater.

Defining the limiting organic loading rate for a system must be done on an individual basis. However, rule of thumb rates have been developed based on experience. Thomas[6] cites 25 lb/acre/day as a loading rate at which decomposition will approximately balance organic matter accumulation. For infiltration-percolation systems, a maximum BOD loading rate of 200 lb/acre/day has been suggested as the safe loading rate for pulp and paper wastewaters[7]. Substantially higher loading rates (greater than 600 lb/acre/day) have been used on a short term seasonal basis for infiltration-percolation systems. For overland flow systems, organic loadings in the range of 40 to 100 lb/acre/day have been successfully used[5].

Inorganics — Dissolved inorganic constituents are those with the broadest impact on land treatment systems. They include TDS, nitrogen, phosphorus, exchangeable cations, and trace elements.

TDS — The TDS content, which is related to the EC (electrical conductivity) is generally more important than the concentration of any specific ion. Unless proper irrigation management is practiced, high TDS wastewater can cause a salinity hazard to crops, especially in arid and semiarid areas. Salt buildup in the groundwater as a result of irrigation with effluent may limit large-scale use in some hydrologic basins.

Nitrogen — Nitrogen can be removed in soil treatment systems by crop uptake and harvest or by denitrification. Crop uptake is the major removal mechanism in irrigation and can account for 50 to 600 lb/acre/year of nitrogen depending on the crop and yield. Denitrification may be significant for overland flow and infiltration-percolation systems depending on the hydraulic and organic loadings and the creation of anaerobic conditions[8,9]. All nitrogen forms interact within the soil but the nitrate form is mobile and can pass through the soil to the groundwater.

Phosphorus — Phosphorus contained in wastewater occurs mainly as inorganic compounds, primarily phosphates, and is normally expressed as total phosphorus. Phosphorus removal is accomplished through plant uptake and by fixation in the soil matrix[10]. Long term loadings of phosphorus are important because the fixation capability of some soils may be limited over the normal expected life span of the system. Phosphorus that reaches surface waters as a result of surface runoff or interception of groundwater flow may aggravate problems of eutrophication.

Exchangeable cations — Exchangeable cations, particularly sodium, calcium, and magnesium ions deserve special consideration. High sodium concentrations in clay-bearing soils have the effect of dispersing the soil particles and decreasing the soil permeability. To determine the sodium hazard, the sodium adsorption ratio (SAR) has been developed by the U.S. Department of Agriculture Salinity Laboratory[11]. High SAR (greater than 9) values may adversely affect the permeability of soils[12]. Other exchangeable cations, such as ammonium and potassium may also react with soils. Occasionally high sodium concentration in soil can also be toxic to plants, although the effects on permeability will generally occur first.

Trace elements — Although many trace elements are essential in varying degrees for plant growth, some become toxic at higher levels to both plant life and microorganisms. Retention of trace elements such as heavy metals in the soil matrix is by adsorption and ion exchange, although removal of metals from solution by precipitation does occur to some extent, especially in the presence of sulfides. Retention capabilities are generally good for most metals in most soils, especially for pH values above 7. Under low pH conditions, metals can be leached out of soil systems. Boron is another trace element that may be toxic to certain plants at concentrations above 0.5 mg/1.

Crops/Vegetation

Crops or vegetation to be planted may be selected based on various factors: high water and nutrient uptake, such as for hydrophytic grasses; high salt tolerance (bermuda grass); high market value, such as alfalfa or corn; or low management requirements. When the crop is selected for its high market value, a careful analysis must be made of the wastewater to ensure that no constituents are present in concentrations that would affect the yield expected. Perennial grasses with market potential are generally favored for land application systems.

System Components

A land application system may be composed of a number of distinct components from the following categories:

- Preapplication treatment
- Transmission
- Storage
- Distribution
- Recovery of renovated water
- Monitoring

Typical distribution systems for the major types of land application will be described and design criteria will be discussed. These systems include solid set spraying, center pivot spraying, spreading basins, and overland flow using solid set spraying. Design criteria for other system components are discussed in *Evaluation of Land Application Systems*[13].

Solid Set Spraying (Buried) – Solid set spraying using buried pipe is used primarily for spray irrigation systems, but it may also be used for infiltration-percolation and overland flow systems. The major design variables include: sprinkler spacing, application rate, nozzle size and pressure, depth of buried pipe, pipe materials, and type of control system. For more detailed information, additional references, such as *Sprinkler Irrigation*[3], should be consulted.

- Sprinkler spacing — May vary from 40 by 60 feet to 100 by 100 feet and may be rectangular, square, or triangular. Typical spacings are 60 by 80 feet and 80 by 100 feet.
- Application rate — May range from 0.16 to 1 in./hr, with 0.2 to 0.25 in./hr being typical. Weekly rates vary with climate, soil type, and crop requirements over the ranges indicated in Table 1.
- Nozzles — Generally vary in size of openings from 0.25 inch to 1 inch. The discharge per nozzle can vary from 4 to 100 gpm with a range from 8 to 25 gpm being typical. Discharge pressures can vary from 30 to 100 psi, with 50 to 80 psi being common.
- Depth of buried laterals and mainlines — Dependent on the depth of freezing for cold climates. Where the depth of freezing is not a factor, a depth of 18 inches for laterals, and 36 inches for mainlines is common[2]. Surface piping, usually of aluminum, may be 40 to 50 percent less costly than buried piping, but it is also less durable.
- Pipe materials — Any type of standard pressure pipe may be used; however, asbestos-cement and plastic (PVC) pipe are most common. Factors that should be considered when selecting type of pipe material include: cost, strength, ease of installation, and reliability.
- Control systems — May be automatic, semiautomatic, or manual. Automatic systems are the most popular for land application systems. Automatic valves may be either hydraulically or electrically operated.

Center Pivot Spraying – Center pivot spraying systems are most commonly designed to irrigate areas ranging from about 35 to 135 acres per unit. Units may be driven electrically, hydraulically, or mechanically, and may be designed to complete one revolution in a period ranging from 8 hours to as much as 1 week. Standard operating pressure is generally 50 to 60 psi. More detailed information can be obtained from the supplement to the third edition of *Sprinkler Irrigation*[2].

Infiltration Basins – This method is the most common for infiltration-percolation systems. The major design variables include: application rate, basin size, height of dikes, and maintenance of basin surfaces.

- Application rates — Can vary from 4 to 120 in./wk, with the range of 12 to 24 in./wk being most common. Loading cycles generally vary from 9 hours to 2 weeks of wetting with 1 day to 3 weeks of drying.
- Basin size — Generally a function of design flow and relationship of wetting and drying periods. Basins may range in size from less than 1 acre to around 50 acres. It is usually necessary to include at least 2 separate basins for even the smallest of systems.
- Height of dikes — Will vary with depths of water applied. For depths of 1 to 2 feet, a height of dikes of approximately 4 feet is common.
- Maintenance of basin surface — May be a significant operation and maintenance expense. Many

systems require periodic tilling of surface, often annually, while some high-rate systems may require periodic replacement of sand or gravel.

Overland Flow – The most common method of application for overland flow systems is solid set spraying using buried pipe. Consequently, most of the ranges of design variables discussed for solid set spraying are applicable; the most significant difference is sprinkler spacing. Lateral spacing is determined by terrace width, which may range from 150 to 300 feet. Sprinkler spacing along laterals may range from 40 to 80 feet. The terraces, which are an integral part of the distribution system, may range in slope from 2 to 6 percent. The most common hydraulic loading cycles are 6 to 8 hours of wetting and 16 to 18 hours of drying, depending on climate and time of year[5].

CASE STUDY

To illustrate the general design considerations that have been presented, a case study of a preliminary land application system design will be discussed. A discussion of the background and preliminary engineering functions will precede the analysis of the available alternatives.

Background

Metcalf & Eddy, Inc., was recently retained by the Baltimore District, Corps of Engineers, to design a land application system for Fort George G. Meade, Maryland. Fort Meade is located between Baltimore and Washington, D.C., near the Baltimore/Washington International Airport. Because the contract for services was issued after the first of November, 1974, the work on design concepts and parameters has only recently begun. However, the project has a number of interesting facets and will serve to illustrate how combinations of land application methods can be utilized in design.

A preliminary engineering report was prepared and submitted to the Corps in June, 1973[14], in which implementation of spray irrigation as the means of liquid wastewater disposal was recommended. A reconnaissance level study of the available lands defined the limits of the area that would be suitable for receiving an effluent application rate of 2 inches per week. The land treatment system was to include an aerated lagoon, a storage lagoon, chlorine contact tank, pumping station, sprinkler irrigation system, and an administration building. Secondary clarifiers and an aerobic digester were also proposed for solids capture and treatment.

The site selected for effluent irrigation is shown in Figure 3. The site is bounded on the south and west by the Little Patuxent River, on the north by a railroad and warehousing complex, and on the east by several firing ranges. Also, located at the northwest corner is the Tipton Army Airfield, which serves the smaller aircraft associated with the post. One additional important feature is Soldiers Lake, a small, manmade lake located in the northeast corner of the site. This lake provides some leisure-time fishing for the military personnel.

Site characteristics of special interest to land treatment are summarized as follows:

- Land area — 725 acres
- Elevations — 120 to 225 feet
- Slopes —
  overall, 0 to 12 percent
  average, 5 to 10 percent
- Vegetation —
  regrowth of pine, 30 percent older pine and hardwoods, 70 percent
- Soils — loamy sands to clay loams

A major part of the site is presently being used as an impact area for small arms ranges. These ranges are heavily used, especially during the summer and fall months, and there are no plans for relocating the ranges. This site characteristic is obviously not a normal design parameter for an effluent irrigation system. It does, however, dictate that special consideration be given to selection of hardware, pipeline location, pipeline materials, operational procedures, and remote controls.

Another major consideration in the design of sewage treatment and disposal facilities is the discharge quality criteria. Recent meetings between the USEPA, Region III; Baltimore District, Corps of Engineers; U.S. Army Environmental Hygiene Agency; Maryland Water Resources Administration; and Maryland Environmental Health Administration resulted in several conclusions. The conclusions are summarized in Table 2.

Table 2. SUMMARY OF APPLICABLE WATER QUALITY CRITERIA

Quality prior to land application	
Secondary treatment and disinfection	
BOD	
30-day mean	≤30 mg/1
7-day mean	≤45 mg/1
Total coliform bacteria	≤3 colonies/100 ml
Quality of groundwater	
Natural groundwaters below the site	≤1962 PHS drinking water standards
Seepage or groundwater underflow to Little Patuxent River	
Total nitrogen (N)	≤3 mg/1[a]
Total phosphorus (P)	≤8 mg/1[a]
Total coliform bacteria	≤MPN 70/100 ml[a]

[a] Allowable increase above existing groundwater quality.

These criteria are in contrast to the criteria for discharge to surface waters, as presented in the 1973

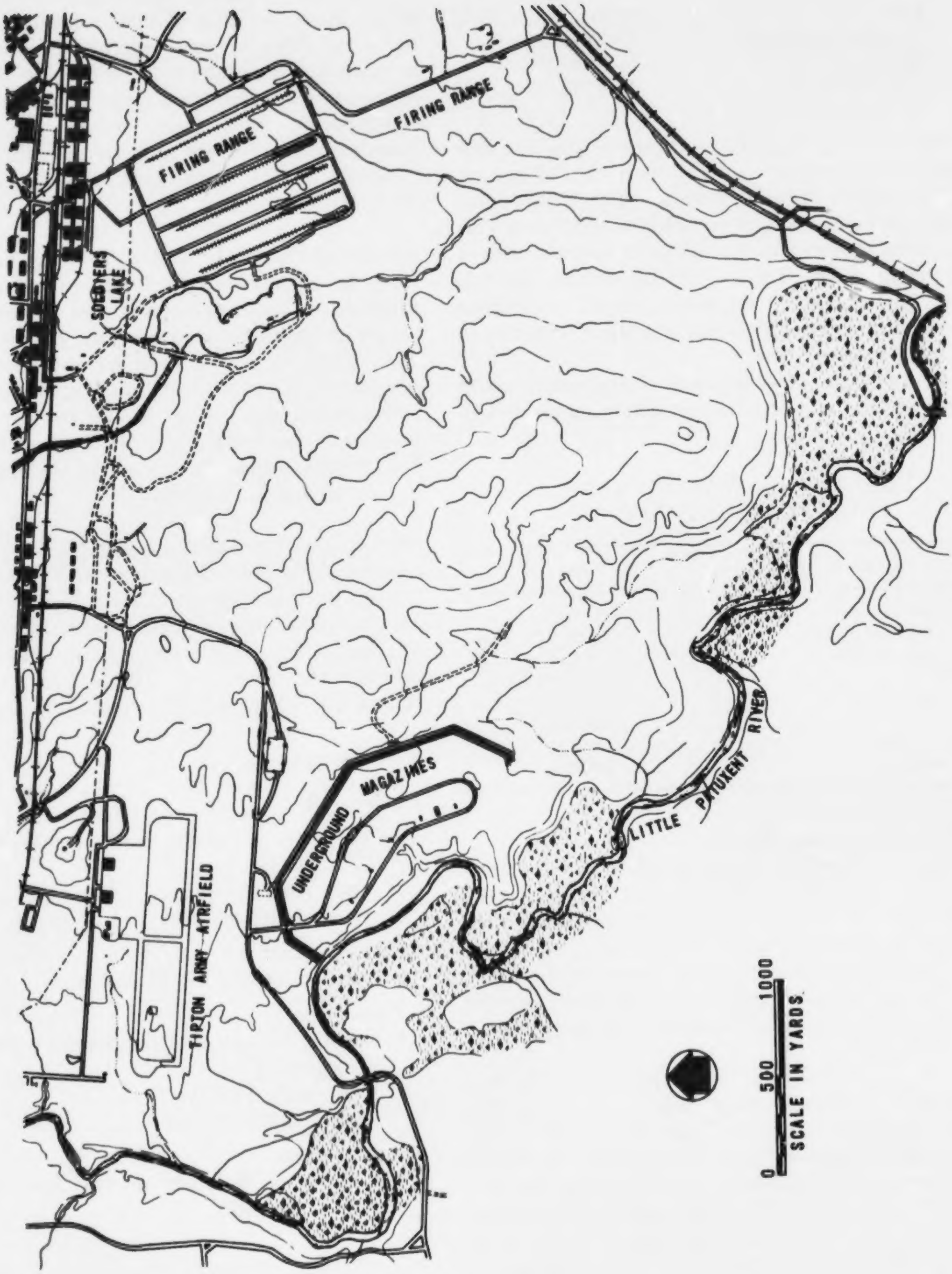

FIRING RANGE
FIRING RANGE
SOLDIERS LAKE
UNDERGROUND MAGAZINES
TIPTON ARMY AIRFIELD
LITTLE PATUXENT RIVER
0
500
1000
SCALE IN YARDS

FIGURE 3. SITE PLAN FOR LAND TREATMENT SYSTEM

preliminary report. At that time, effluent quality requirements were as follows:

BOD	≤10 mg/1
Ammonia nitrogen (N)	≤1.0 mg/1
Organic nitrogen (N)	≤1.0 mg/1
Dissolved oxygen	≥4.0 mg/1

Nitrification was required by these criteria, but subsequent correspondence (1973) with the Maryland Water Resources Administration resulted in an indication that both nitrogen and phosphorous removals may soon be required for discharge to water bodies of the Patuxent River Basin. For this reason, an advanced wastewater treatment plant, including nitrification and denitrification, was the alternative to a land treatment system.

The available raw wastewater characteristics and the present and projected flows are summarized in Table 3.

Table 3. RAW WASTEWATER CHARACTERISTICS (14)

Parameter	Value
Flowrate, mgd	
Present average (1973)	2.9
Design average (2000)	4.6
BOD, mg/1	160-235
Total nigrogen (N), mg/1	22-34
Total phosphorus (P), mg/1	9.0-10.9
Suspended solids, mg/1	152-392
Total solids, mg/1	490-810

Preliminary Engineering Functions

Having developed the background to the problem, the actual work of engineering can be described. Because the work has not yet been accomplished, firm results and conclusions cannot be presented. However, a general description of the tasks that have either been initiated or will be performed during the program are discussed in the following paragraphs.

Soil Survey – A soil survey was performed by the Soil Conservation Service during August, 1974, for the Baltimore District, Corps of Engineers and the report was submitted October 15, 1974. The study was keyed to the existing Soil Survey of Anne Arundel County, Maryland, issued in 1973. A summary of the major soil limitations mapped in that report is shown in Figure 4. One purpose of this survey was to define the infiltration capacity of the various soils.

Geological Investigation – This work was started in the field on November 4, 1974, and should be completed by January, 1975. The work is being done by the Geology and Foundation Section, Baltimore District, Corps of Engineers. Two objectives are to be accomplished under this program. The first is to develop a detailed description of the site geology, showing detailed lithology in at least two sections. Special note is to be made of fault zones, fracture trace intersections, open bedding planes, or any other discontinuities. Also a good picture of the underlying groundwater contours is to be developed. The second objective is to establish a series of monitoring wells in coordination with their drilling and exploration program. These wells are to be suitable for both baseline quality data and also for a continuing monitoring program.

Monitoring Program – The U.S. Army Environmental Hygiene Agency is performing a sampling and testing program in conjunction with the Baltimore District, Corps of Engineers and the Post Facilities Engineer. They have assisted in defining and coordinating the program to date and will continue through the design and construction phase of the project. There is a possibility that CRREL (Cold Regions Research and Engineering Laboratory) may become the lead agency in this area after startup.

Climatic Data – Data are available from both the records of Fort Meade and the U.S. Weather Bureau Station at the Baltimore/Washington Airport. The data are now being compiled and analyzed by Metcalf & Eddy to develop a water balance and to determine storage requirements. The climatic parameters assumed initially as being applicable are:

Precipitation

- Wettest year in 10 — 51.0 in./yr
- Average annual — 41.4 in./yr
- Number of days with precipitation over 0.1 inch —
  - per year, 74 days
  - per month, 8 days

Evapotranspiration

- Average annual — 30 in./yr

Temperature

- Number of days that temperature remains below 32 degrees F —
  - per year, 14 days
  - per month, 6 days

Wind Velocity

- Number of days per month that wind velocity exceeds 15 mph

Water Balance – From the climatic data, the number of days that the spray system would probably not operate can be estimated. From the data on infiltration estimates, precipitation, evapotranspiration, and wastewater flows, an annual water budget will be developed. The results of these data will be used to estimate the land area required for the design wastewater flow, unless limited by some other parameter.

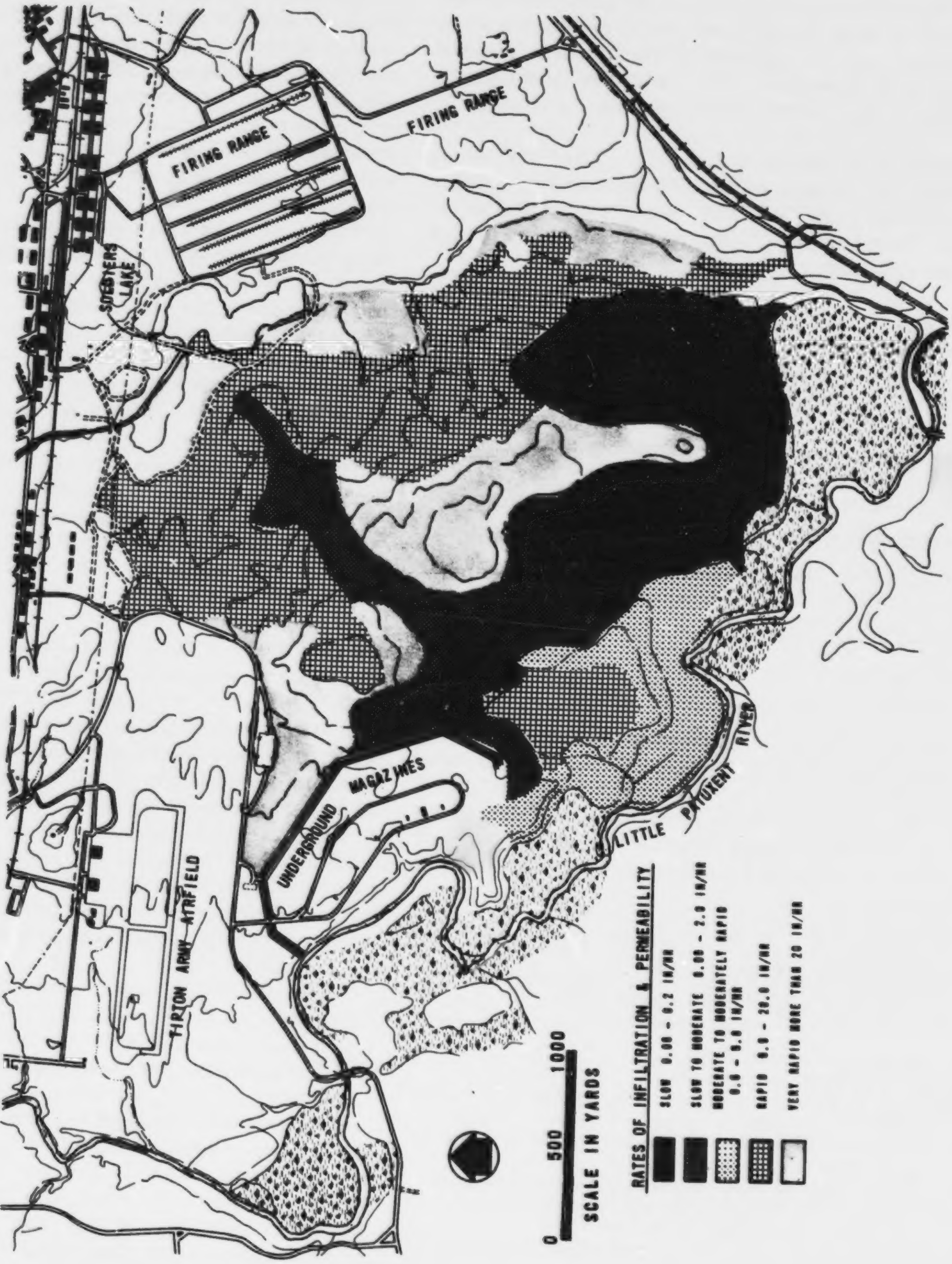

FIRING RANGE
FIRING RANGE
SOLDIERS LAKE
UNDERGROUND MAGAZINES
TIPTON ARMY AIRFIELD
LITTLE PATUXENT RIVER
0 500 1000
SCALE IN YARDS
RATES OF INFILTRATION & PERMEABILITY
SLOW 0.00 - 0.2 IN/HR
SLOW TO MODERATE 0.06 - 2.0 IN/HR
MODERATE TO MODERATELY RAPID 0.6 - 6.0 IN/HR
RAPID 6.0 - 20.0 IN/HR
VERY RAPID MORE THAN 20 IN/HR

FIGURE 4. SOIL INFILTRATION RATES FOR LAND TREATMENT SITE

Nutrient Balance — Based on the amount of available nutrient in the wastewater, the amount of nutrient removal that may be expected from the vegetative cover or treatment method, and the allowable effluent quality criteria, the land area developed from a water balance must be checked. If the nutrient removal capacity is inadequate, then additional land must be added or the treatment method must be changed.

Preparation of Construction Plans — After the water balance and nutrient balance (or balance for any other wastewater constituent that may prove critical) have been completed and the land area selected, the physical system can be designed.

Alternative Treatment Plans

Although all necessary data are not available at this time, there are sufficient data to make a preliminary assessment of the suitability of various land treatment methods or combinations of methods. The most critical parameters are the following:
2100

- Hydraulic loading (water to be treated)
- Nitrogen removals
- Operating time—suggested by owner (40 hr/wk) established by climatic conditions
- Soil characteristics
- Vegetative cover
- Available land area

All three basic land treatment methods are being considered, including (1) spray irrigation, (2) overland flow followed by additional treatment and/or disposal, and (3) infiltration-percolation followed by spray irrigation. Seven alternatives were developed from these methods for review and they are listed in Table 4.

Table 4. LAND APPLICATION ALTERNATIVES AT FORT MEADE

1. Spray irrigation of woodlands
2. Spray irrigation of grasslands
3. Spray irrigation of a combination of grass and wooded lands
4. Overland flow followed by direct discharge to Little Patuxent River
5. Overland flow followed by spray irrigation of woodlands
6. Overland flow followed by infiltration-percolation with withdrawal and discharge to the river
7. Infiltration-percolation and pumped withdrawal followed by irrigation of grasslands

Note: All of the above alternatives would be preceded by aerated lagoon, storage lagoon, and disinfection, if necessary.

Spray Irrigation — There are 3 alternatives involving spray irrigation as the treatment and disposal method. Alternative 1 involves spray irrigating the existing pine and hardwood forest. Based on the nitrogen uptake of forests observed at Penn State[15], a removal of approximately 100 lb/acre/yr of nitrogen can be expected. When 4.6 mgd of effluent containing 25 mg/1 of total nitrogen is applied over 700 acres of land, the resulting areal loading is 500 lb/acre/yr of nitrogen. If 100 lb/acre/yr is removed, the remaining 80 percent of the nitrogen applied will ultimately reach the groundwater at a concentration of 20 mg/1, mostly as nitrate-nitrogen. Because this exceeds the discharge standards, Alternative No. 1 should be rejected.

If 10 mg/1 is the maximum nitrogen permissable in the groundwater, there must be a 60 percent or more reduction of the nitrogen applied. In other words, a vegetative cover must be found that will take up approximately 300 lb/acre/yr of nitrogen. Reed canary grass was found at Penn State to satisfy this goal[15] and other grasses are probably available. Nearly the entire site would have to be cleared and planted to grass for Alternative No. 2 to meet the nitrogen loading. The actual area required would be 640 acres, based on a nitrogen uptake of 400 lb/acre/yr. Consequently, Alternative No. 3, with irrigation of a combination of grass and forested areas does not appear practical because there would be little, if any, forested area remaining.

Overland Flow — Pilot scale work using municipal wastewater (reported by Thomas[16]) and bench scale work (reported by Hoeppel, et al.[17]) have been conducted for overland flow treatment. Nitrogen removals reported in these studies are consistently 80 to 85 percent and more. Results of full scale operations reflect these same high removals[18]. The effluent in these studies was highly nitrified, which would be acceptable for discharge under the 1973 standards. Under requirements of 90 percent nitrogen removal, however, overland flow alone should not be relied on to meet the discharge criteria, consequently Alternative No. 4 is not considered viable.

Alternative No. 5, in which overland flow would be followed by spray irrigation, and Alternative No. 6, in which it would be followed by infiltration-percolation and discharge to surface waters are considered viable. In Alternative No. 5, a loading rate of 0.7 in./day is used to establish the land requirement. This area is then increased to allow time for nonoperation during freezing weather and during crop harvest. The field area required for overland flow is 400 acres. Because the upper portions of the site exhibit the less permeable loamy and clayey soils, this area would be utilized for overland flow. The remaining area would be kept as forest, except for installation of spray lines and roads.

In Alternative No. 6 the spray irrigation component would be replaced with infiltration-percolation. As in Alternative No. 5, approximately 30 percent of the water applied to the overland flow system would be lost to percolation and the remaining 3.2 mgd would be collected. This renovated effluent would then be spread in infiltration-percolation basins, covering 80 acres of the most permeable soils. After renovation by the soil, the water would be pumped out and discharged to surface waters. In effect, the infiltration-percolation process would be used as a polishing filter. The quality of the renovated water should exceed the discharge requirements.

Infiltration-Percolation – Alternative No. 7 would involve infiltration-percolation of secondary effluent followed by pumped withdrawal and spraying of renovated water on grassland for disposal. Based on work by Bouwer[19] at Flushing Meadows, Arizona, a well managed infiltration-percolation system can attain 30 percent nitrogen removal. The combination of natural filtration that would greatly reduce BOD, suspended solids, and coliforms, followed by spray irrigation for nitrogen removal by plant uptake could be feasible for this project. Because of the 30 percent reduction in nitrogen loading, the area required for spray irrigation would be reduced to 450 acres. The land area required for the infiltration-percolation system would be 170 acres, based on an application rate of 7 in./wk.

Cost Comparison of Alternatives

On the basis of this cursory review of the available alternatives, three were screened as not being viable. The remaining four alternatives are listed in Table 5 along with the estimated capital costs. The cost estimates are very rough and do not include such items as preapplication treatment, piping to the land application site, roads, or allowances for contingencies, administration, or engineering. The costs do include storage, site clearing, distribution systems, pumping, and collection of renovated water. The costs are indexed to the EPA Sewer Construction Index for July 1974 in Baltimore. The basis of this cost comparison is a draft report prepared by Metcalf & Eddy, Inc., on *Costs of Land Application Systems*[1], which is undergoing review by the Environmental Protection Agency. Operation and maintenance costs, for which cost curves are also included in the EPA report, are not included here.

The selection of the best alternative will be based on the results of a cost-effectiveness analysis, the ability to meet the water quality criteria, and considerations of land use and impacts on the environment. As the detailed aspects of each alternative are considered, refinements and modifications that affect the costs probably will occur. In addition to the soils information previously described, more detailed data on the geology and soil profile may be required for the areas selected for infiltration-percolation.

Table 5. PRELIMINARY COST COMPARISON OF LAND APPLICATION ALTERNATIVES AT FORT MEADE

Alternative No.	Description	Construction cost, $(millions)
2	Spray irrigation of grasslands	2.75
5	Overland flow followed by spray irrigation of woodlands	2.69
6	Overland flow followed by infiltration-percolation with discharge to the river	1.95
7	Infiltration-percolation followed by spray irrigation of grasslands	2.40

Note: Costs are for July 1974 and do not include land, piping to the site, pretreatment, contingencies, or engineering.

CONCLUSION

A brief review of the various land application methods was presented including some of the engineering criteria that serve to differentiate the methods. A preliminary analysis of an actual case study was included to illustrate how the different land application methods can be combined to overcome restrictions in topography, soil permeability, and water quality criteria. It is important that the engineer dealing with land application of effluents does not attempt to transfer the operational features and design parameters from another geographical area to his specific case without giving consideration to all of the different conditions. Land treatment methods should be considered as unit processes in much the same way as sanitary engineers have long considered the various conventional treatment processes. The various treatment methods should be selected or combined in such a way as to provide a design that is tailored to the specific site and its limitations.

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Public Health Aspects of Land Application of Wastewater Effluents

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INTRODUCTION

The goal of land treatment is the treatment of wastewater in an economically, socially and environmentally acceptable manner to produce high quality renovated water while concurrently producing useable crops.

The environmental and public health aspects of recycling municipal wastewaters on the land are dependent upon a number of variables. One important variable is the ultimate use of the partially renovated wastewater. Uses may include discharge to a surface body with or without percolation through the soil; groundwater recharge; crop irrigation; and, obviously, any combination of the three.

The method of application of the wastewater is another important variable. Of primary interest are the overland flow, rapid infiltration and spray irrigation application methods, each of which has distinct requirements with respect to soil character, crop cover and application rate. Selected characteristics of several land application systems can be found in Table 1.

In general, the basic environmental and public health considerations will be similar, despite the conditions of wastewater ultimate use, pretreatment and application technique. However, once a set of design variables are selected, emphasis must be placed on those concerns which are most critical to the selected variables.

In a discussion of this nature, due consideration must be given to the physical, biological and chemical aspects of the problem.

Table 1. SELECTED CHARACTERISTICS OF LAND APPLICATION SYSTEMS

	System		
Factor	Overland Flow	Rapid Infiltration	Spray Irrigation
Application rate	8-15 ft/yr	15-400 ft/yr	2-8 ft/yr
Land required for 1mgd flow (net)	75-140 acres	3-75 acres	140-560 acres
Desired soil permeability	Low	High	Moderate
Probability of influence on ground water	Slight (20%)	Certain (90%)	Probable (70-30%)
Evaporation	20%	10%	30-70%
Treatment effectiveness	Moderate	Low	High

PHYSICAL CONSIDERATIONS

Physical considerations of land application of wastewaters are somewhat secondary, in that they relate, to a large degree, to both the biological and chemical considerations. Particular attention must be paid to the removal of suspended material which will insure that both the distribution system and the soil treatment system do not become clogged. The physical characteristics of the soil treatment system are infinitely important. Wide variations in soil characteristics make it mandatory that each potential land application site be studied intensely before land application practices are instituted. As will be developed shortly, the physical characteristics of the soil and the application system are intimately related to both the biological and chemical aspects of municipal wastewater land application.

"The opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense."

BIOLOGICAL CONSIDERATIONS

With regard to the biological considerations, pathogens in wastewater represent one of the major potential health problems associated with recycling municipal wastewaters on the land. This problem can manifest itself in two ways: contamination of groundwaters used for public water supply and dissemination of pathogenic aerosols which may be inhaled by man or animals in or near the application site. (Sorber, 1973)[1].

Pathogen Concentrations in Wastewaters

The number of pathogens found in municipal wastewaters varies widely depending on the time of year and the community. For example, estimates of virus concentrations from field studies have indicated concentrations up to 7000 plaque forming units (PFU/liter for raw sewage to about 50-1600 PFU/liter for chlorinated secondary effluents. (Sorber, *et al.*, 1972)[2]. In fact, recently, Buras (1974)[3] found an average of 56,000 PFU/liter in secondary effluent by using her direct inoculation technique.

It has been demonstrated repeatedly that many pathogens, especially viruses, pass conventional waste treatment processes even though they have been reduced in number. As Berg (1973)[4] accurately points out, primary and secondary treatment processes reduce the numbers of viruses only slightly. Although some laboratory studies have shown good results, field evaluations are, at best, erratic.

In actual practice, disinfection probably plays the most important role in reducing pathogen concentrations in wastewater. However, much of the classical data on disinfection does not resemble real world conditions. Disinfection as practiced in wastewaters is often far less effective for pathogens, especially viruses, than it is for indicator bacteria. Table 2 contains recent field data which affirms this contention.

Table 2. EFFECT OF WASTEWATER TREATMENT ON VARIOUS ORGANISMS
(After Sorber, *et al*, 1974)[5]

	Total Reduction in Treatment Plant (Log_{10})	Reduction by Chlorination Only (Log_{10})
PLANT #1*		
Fecal Coliform	3.7	2.1
Fecal Streptococci	2.4	2.0
Salmonella †	1.4	0.5
Enteric Viruses ¶	0.4	0.3
PLANT #2 δ		
Total Coliform	6.8	5.5
Fecal Coliform	5.8	3.6
Klebsiella α	5.2	3.7
f_2 Bacteriophage	—	0.9**

* Standard-rate trickling filter; chlorine residual approximately 1.5 mg/1.

† Presumptive. M-bismuth sulfite broth with MF procedure.

¶ Three days on BGM cells after concentration (Schaub and Sorber, 1974)[6].

δ High-rate trickling filter; chlorine residual approximately 4 mg/1 with improved mixing.

α Large number confirmed as *Klebsiella* on differential media.

** After Kruse, *et al.* (1973)[7].

Pathogens in Soils

The application of wastewater to soil has been studied to some extent with regard to pathogen mobility and destruction in soils (Sorber, *et al.*, 1972)[5]. Basically, pathogen removal in soils is a function of the characteristics of the soil. Under certain conditions, such as limestone crevicing, pathogens have been found to travel miles. On the other hand, heavily textured clay soils, thru adsorption and filtration, can remove viruses, bacteria and the larger pathogens, on and near the soil surface.

Those pathogens which are collected on or in soil can be inactivated after land application. Exposure to ultraviolet light, oxidation, desiccation and antagonistic soil organisms are the most important destructive mechanisms. Conversely, there is ample literature citation to indicate that some pathogens can survive these deleterious effects in soil for relevantly long periods.

It has been shown that coliform organisms do not survive in soil and on vegetation as long as certain other bacteria such as *salmonella, klebsiella,* and some worm eggs. Virus survival on soil is essentially unexplored. It is likely, however, that viruses will survive longer than coliform organisms. It is important to know whether pathogenic organisms can survive on soil and vegetation for extended times.

It is also important to consider pathogen concentration on or near the soil surface. Consideration should be given to the effects of long term application of nondegradable organic materials that may clog the soil surface or tie-up soil adsorption sites; the effect of cation species and concentration with respect to soil tightness and adsorption; the effects of high pH on soil filterability and reduced adsorption capability; and lastly, the reduced treatment capabilities of soil for pathogens after shock loading of a toxic effluent (from spills).

These possibilities suggest some reasonable, potential public health implications. Human contact with organisms on soil surfaces may result if winds, machinery, or other human activity such as walking reaerosolize the organisms and make them accessible for inhalation. Runoff, either during intense effluent application or precipitation, may cause significant numbers of concentrated pathogens to enter surface waters. Obviously this problem can be minimized by proper design of the application site.

Pathogenic Aerosols

In evaluating the potential problems associated with pathogenic aerosols consideration must be given to wastewater pathogen concentration and treatment effectiveness, amount of wastewater aerosolization, receptor distance from the sample and the prevailing meteorological conditions.

Aerosols are defined as particles in the size range of .01 to 50 or so micrometers (μm) which are suspended in air. Direct means of human infection by biological aerosols is by inhalation. The infectivity of a biological aerosol is further dependent on the depth of respiratory penetration. Biological aerosols in the 2-5 μm size range are primarily captured in the upper respiratory tract. These particles are removed by the bronchial cilia and may ultimately pass into the digestive tract. If gastro-intestinal pathogens are present in the aeosols, a certain degree of infection may result. However, a much higher incidence of infection will result when respiratory pathogens are inhaled into the alveoli of the lung. The greatest alveolar deposition occurs in the 1-2 μm range and then decreases to a minimum at approximately 0.25 μm. Below 0.25 μm, deposition again increases due to Brownian movement in the lungs. It is imperative, therefore, to have knowledge of the size and distribution of aerosols generated by spray irrigation equipment under various meteorological conditions.

Specific studies of biological aerosols emitted by spray irrigation of wastewater have not been found in the literature. Some investigations have been conducted on biological aerosols from trickling filters and activated sludge systems. In general, it was found that bacterial aerosols remain viable and travel further with increased wind velocity, increased relative humidity, lower temperatures and darkness.

For a given set of meteorological conditions, the amount of wastewater aerosolized during spray irrigation is a function of the spray equipment and operating conditions employed. There are many design choices of spray equipment such as the solid set, rain gun and center pivot configurations. Research is under way to determine the amount of wastewater aerosolized and the particle size distribution for each of these spray configurations under various meteorological conditions. These studies have provided several preliminary conclusions worthy of mention:

(1) Aerosols generated and leaving the immediate vicinity of various spray irrigation rigs represents only a fraction of one percent of the total applied test water.

(2) The average particle diameters of the droplets making up the aerosol are in the 1-2 μm size range. Evaporation or dessication will significantly reduce the aerosol's particle size, with the eventual size being a function of the total solids content of the wastewater. Suffice it to say that we are dealing with particles that are small enough both to remain suspended in the atmosphere for considerable time and to penetrate and be deposited in the lower respiratory tract.

(3) Although wind has always been considered important in controlling aerosol transport, this study has shown that wind is very significant in aerosol generation. Greater aerosol is produced when sprays are into the wind, than when sprays are at right angles to or away from the wind. With most sprinklers involving 360 degrees rotation, and winds subject to frequent changes in direction, control of aerosol production by orientation of the spray with wind direction seems an unreasonable approach to reducing potential health hazards.

This study characterizes total aerosol output by irrigation machinery and does not provide much insight as to aerosolized pathogens. Their concentration, being some percentage of the total aerosol, may be influenced by a variety of meteorological conditions, such as relative humidity, wind velocity, stability, sunlight and temperature.

Sunlight, through ultraviolet radiation, can be deleterious to microorganisms including viruses. Its effectiveness is significantly reduced at night and under overcast conditions. Increased temperature can reduce the viability of viruses, but mainly to the extent of accentuating the effects of relative humidity (Watkins, *et al.*, 1965)[8]. The more pronounced effects do not appear until temperatures exceed 80°F, an unlikely consistent condition in most parts of the United States. The effects of temperature and sunlight, therefore, can not be relied upon to provide significant reductions in aerosolized pathogens for most conditions.

Stability conditions and wind velocity are closely related. As indicated earlier, the role of wind velocity is important as it relates to the spray equipment chosen, and consequently, the amount of aerosol generated. Herein lies a major conflict. Although high wind velocities result in larger amounts of aerosols generated at the nozzle, stable atmospheric conditions, characterized by low wind velocities and darkness, result in higher concentrations of aerosol at a downwind centerline position. It may well be that to design for optimum wind velocity and stability conditions may limit operating time and, therefore, be undesirable.

In general, relative humidity appears to have the most pronounced effect on the viability of aerosolized viruses and bacteria. Many enteric viruses exhibit a similar trend: low survival at low relative humidities and high survival at high relative humidities. Generally, bacteria and some bacteriophage show high survival at both low and high relative humidities, with low survival at middle relative humidities.

The apparent advantages of low relative humidities for viruses may be negated for two reasons. DeJong, *et al.* (1974)[9] in developing relative humidity data for EMC viruses showed the infectious RNA was essentially unaffected over the entire relative humidity range despite a more classical response for test system infectivity of the virus. A second factor is illustrated by the data in Table 3. For the northeastern site, the relative humidity is 60 percent or higher 63 percent of the time and 80 percent or higher 35 percent of the time. In either case, depending on relative humidity to provide substantial virus die-off would seem to be inadvisable.

Table 3. FREQUENCY OF OCCURRENCE FOR RELATIVE HUMIDITY

Relative Humidity (Percent)	Time Greater Than (Percent)	
	Northeastern Site	Southwestern Site
20	>99	80
40	89	44
60	63	21
80	35	7

It is reasonable to postulate that, if disinfection of sewage is not complete and if pathogenic organisms are aerosolized, evern very low numbers of these organisms may be a potential public health hazard. In an effort to evaluate this situation, we have developed models describing the potential human risk for a variety of wastewater pathogen conditions, meteorological conditions, and treatment schemes (Sorber, *et al.*, 1974)[5]. Unfortunately, field validation of these predictions is not yet available. In all, this is a large area which needs complete exploration.

It is interesting to relate the potential aerosol problem to spray area design criteria. Predictions through modeling indicate a 2-log reduction in virus concentration can be achieved with an 800 meter buffer zone. For comparative purposes, it is assumed that filtration followed by disinfection with adequate mixing will provide approximately a 3-log reduction in the virus concentration. For operation conditions, such as those planned for Muskegon, Table 4 presents a comparison of costs for these two alternate situations at various normal design flows.

Table 4. COMPARISON OF COSTS FOR 800 METER BUFFER ZONE AND FILTRATION AT VARIOUS DESIGN FLOWS
(After Sorber, *et al*, 1974)[5]

	Nominal Design Flow (mgd)			
	5	10	20	40
Spray Area (acres)	700	1400	2800	5600
Buffer Zone (acres)*	1400	1900	2800	3800
Capitol Cost of Buffer Zone Land				
@ $500/acre	$ 700K	$ 950K	$1400K	$1900K
@ $2000/acre	$2800K	$3800K	$5600K	$7600K
Filtration Costs †				
Capitol Cost (Mar 74) δ	$ 485K	$ 775K	$1260K	$1940K
Operating Cost (¢/1000 gal) α	5.1	3.9	3.2	2.4

* Buffer zone of 800 m should provide a 2 log reduction of virus concentration under most meteorological conditions (assumes no protection of virus by solids).

† Filtration followed by disinfection with adequate mixing should provide approximately 3 log reduction in virus concentration.

δ Adjusted to 1974 by ENRCC $\frac{2021}{1039} = 1.94$

α Adjusted to 1974 by factor 1.5

FAUNAL RESPONSES

Considerable interest has developed on the effect of land application of wastewaters on changes in both the populations and the disease incidence among wild animals, birds, and mosquitoes. This interest should be extended to cattle and other animals which may be bred on the land application site as part of the overall resource management program.

In a three-year study by Parizek, *et al.* (1967)[10] at Penn State, it was concluded that there were no measurable changes in the populations of small animals and birds in areas subjected to spray irrigation. These workers, however, felt that the data served only as a basis for measuring future changes inasmuch as the spray irrigation had not altered the vegetation enough to induce differences in bird and mammal populations.

The point is that there are still conspicuous voids in the literature in this general area. Additional information required includes: the fate possible spread and control of protozoan parasites; the possible passive spread of microorganisms by flying insects; and the capacity of wildlife, including migratory birds, to carry infection great distances from a primary focus.

CHEMICAL CONSIDERATIONS

The environmental and public health concerns of recycling municipal wastewaters on land must include organic and inorganic chemical movement in the soil. This topic could be extremely broad if industrial wastes were applied to the land either separately or combined with municipal wastewaters. In this discussion, however, large quantities of industrial wastes will not be considered.

Dissolved Soils

Dissolved chemical substances normally found in water generally increase in concentration when used by man. Water of five Ohio municipalities in one cycle of water use (i.e., raw water source through secondary waste treatment plant) experienced an average increase in total dissolved solids (TDS) concentration of approximately 300 mg/1 (Bunch and Ettinger, 1964)[11]. When treated by land application techniques, water may experience even larger increases in TDS level if passed through certain soil systems. An extreme example of this problem was illustrated at the Imperial California Irrigation District where inflow irrigation water had a TDS concentration of 1242 mg/1 and the outflow contained 3844 mg/1 (Bishop and Peterson, 1969)[12]. Consequently, when land application of wastewater results in recharge of groundwater sources, TDS concentrations could exceed the levels recommended in the *USPHS Drinking Water Standards* (1962)[13]. More important than an aesthetically objectionable TDS level, the associated high sodium content may be harmful to individuals suffering with cardiac, renal and circulatory diseases (McKee and Wolf, 1963)[14].

Heavy Metal and Trace Organic Compounds

Heavy metals or toxic organic compounds are two groups of materials that require special consideration for disposal of wastewaters. Heavy metals, including chromium, copper, lead, manganese and zinc, have increased in concentration in soil where digested sludge was being applied (Hinesly and Sosewitz, 1969)[15].

With regard to trace organics, it is recognized that essentially no information is available as to the specific chemical makeup of municipal secondary wastewater effluents. Consequently, it is difficult to assess the effect of these compounds and their relationship to the environmental and public health aspects of land application of wastewaters.

The movement of dissolved chemicals with percolating water is primarily dependent on the nature of the filtering soil. There have been instances of groundwater contamination of soluble industrial wastes. In one case in Germany, picric acid traveled several miles and caused abandonment of a groundwater supply (Lang and Burns, 1940)[16]. Chemical elements are primarily removed in the soil matrix by the process of ion exchange. Therefore, the chemical clarification ability of soil is proportional to its ion exchange capacity and clay soils, because of their large surface area, have the largest exchange capacities. Cationic exchange, one possible mechanism for the removal of heavy metal ions and ionized organic compounds, occurs until the exchange capacity of the soil is exceeded. Also, they may be released through exchange by other cations.

Pesticides

Pesticides persist in soil and water systems for varying periods, the length of persistence depending on such factors as the chemical nature of the pesticide itself, and the chemical, physical, and biological factors which promote degradation, translocation, or metabolism. Due to the persistence of some pesticides in soil and water systems, consideration must be given to possible build-up of these compounds in the soil at wastewater application sites.

Nitrogen Compounds

Biologically treated domestic wastewater contains 5-30 mg/1 of total nitrogen. The primary source of this nitrogen is the nitrogen metabolism of man. The dominant nitrogen form depends on the specific type of treatment process, but it is usually in the form of ammonia or nitrate. If ammonium ion is the dominant nitrogen form, it will be adsorbed by the soil and, eventually, be used in plant growth or biologically oxidized to nitrate. Therefore, if nitrate is not applied initially, it may be formed biologically on or near the soil surface. Nitrate ions are not adsorbed readily by most soils and, if not utilized immediately by plants, they end up in the groundwater.

Nitrate ion is the causative agent of methemoglobinemia in children. Ingested nitrate is biologically reduced to nitrite in the digestive tract. Nitrite is then absorbed into the blood stream, ultimately causing suffocation by diminishing the ability of the blood to carry oxygen. The *USPHS Drinking Water Standards* (1962)[13] recommended a concentration of no more than 10 mg/1 for nitrate-nitrogen; however, this value has been exceeded in a number of groundwater supplies (Ward, 1970)[17].

Nitrate-nitrogen levels above 10 mg/1 may develop in areas where land application of wastewaters is used for groundwater recharge, and where the recharged groundwater is cycled back through the water supply system.

As pointed out by Lance (1972)[18], the removal of nitrate-nitrogen by denitrification, specifically in a groundwater recharge system, has not been clearly demonstrated and is far from being proven. At present, more research is needed to determine if both nitrification and denitrification can proceed in a soil which is used for land disposal of wastewaters.

CONCLUSIONS

Although this discussion has dealt with a large number of environmental and public health concerns relating to recycling of municipal wastewaters on land, it should be emphasized that some of these problems can be minimized or eliminated by proper site selection, system design and wastewater pretreatment including complete disinfection. To accomplish this end, each of these factors must be considered in light of the ultimate dispostion of the wastewater. Specific conclusions we have developed from this knowledge, or lack thereof, include:

(1) Many of the potential health and environmen-

tal problems can be minimized by proper wastewater treatment.

(2) Site selection is very important.

(3) Pathogenic aerosols near a spray site may be a problem.

(4) Survival of many pathogens in wastewater aerosols and soils is greater than indicator organisms.

(5) Ponding at the land application site will enhance mosquito breeding.

(6) Na^+, NO_3^- and total dissolved solids can be a problem where wastewater recycle is practiced.

Tables 5 through 7 identify research requirements necessary to provide answers to many of the public health and environmental questions related to recycling municipal wastewaters on land. Some of these studies are already underway. Unfortunately, the current level of effort will provide only minor insight into the total knowledge required.

Table 5. PUBLIC HEALTH AND ENVIRONMENTAL RESEARCH NEEDS RELATED TO HUMAN PATHOGENS

The development of sensitive, quantitative pathogen detection techniques (emphasizing viruses) for water, wastewater, soils and spray irrigation aerosols.

The evaluation of the survival, distribution and hazard of aerosolized pathogenic microorganisms disbursed by spray irrigation equipment.

The conduct of a comprehensive epidemiological investigation at a relatively large, operating wastewater land application site.

The comprehensive investigation of pathogen survival and transport in soils, with particular emphasis on viruses.

The investigation of pathogen survival on crops and other vegetation.

Table 6. PUBLIC HEALTH AND ENVIRONMENTAL RESEARCH NEEDS RELATED TO WILDLIFE AND CATTLE

The evaluation of long range effects of land application of wastewater on plant, animal and disease vector ecology.

The evaluation of the capacity of wildlife, including migratory birds, to carry infection or infectious agents great distances from the land application site.

The evaluation of the effects of human and animal pathogens and organic and inorganic wastewater components on domestic food animals raised on feed crops at wastewater land application sites.

Table 7. PUBLIC HEALTH AND ENVIRONMENTAL RESEARCH NEEDS RELATED TO CHEMICAL COMPONENTS OF WASTEWATER

The evaluation of the persistence and translocation of heavy metals in soils at wastewater land application sites.

The characterization and evaluation of the persistence and translocation of pesticides and trace organic constituents of wastewater (and their metabolites) for their potential environmental impact.

The comprehensive investigation of possible mechanisms for the removal and/or conversion of problem inorganic species, especially nitrogen, which may tend to accumulate in groundwaters.

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Educational and Informational Needs for Achieving Public Acceptance

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The basic problem we are concerned with in this discussion is how to get people to think, feel, and act more favorably toward recycling urban effluents and sludges to the land.

For an idea such as recycling urban sewage and sludge to the land to be implemented in our society, it must have public acceptance. It must be acceptable to the majority of the people. It must be actively supported by a large enough number of individual leaders so that they can inform their constituents and keep those who oppose it to a minimum. It must have enough support by both private groups and public agencies so that they will use their organizational, financial, and political strength to bring about its implementation.

We all know that people with vested interests may be very hard to sell on this idea. They may not only be hard to sell but able to block its implementation almost indefinitely, especially if the public feels that they are being treated unfairly or unjustly. Take for example the farmer who may have heard that someone is planning to spread city sludge on his farm. He is not only aware but hostile, fearful, and concerned about what will happen to his land and his family. If this farmer's interests aren't considered and he isn't involved in the planning or if he's treated arrogantly and unfairly, the public and legislators who represent him may decide that equitable and just treatment for him is more important than clean water in a river. Public opinion usually favors an underdog. Also, he may know now only his commissioner and councilman and his senator, and the governor. A surprisingly few such people can block a seemingly good idea for a long time. For these people the survival motive is very strong and they'll give a great deal to protect their interests.

I believe we can agree that the level of public support for this idea at this time is a great deal less than is needed; therefore, we need to devise ways to generate more support—i.e. to develop effective programs to bring it about.

If this idea is to be accepted, we must secure for it a higher place in the mind and active effort of many people. Large numbers of people must become aware and concerned. They must be informed about why it is being considered over other alternatives for disposing of sludge; how it will work; its consequences in terms of such things as dollar costs, effect on health, and on agricultural production and on environment.

People must feel positive and not negative. They must feel supportive of the idea, that it is progressive and not regressive, that it will result in a net gain in environmental quality, and that it is worth the extra costs entailed. Feelings of uncertainty and suspicion must be replaced by reliable factual information and analysis. Feelings of frustration and hostility must be replaced by feelings of mutual trust and dedication to the common goal.

People must be willing to *act* in favor of this idea. For this idea to be adopted, decisions must be made and actions taken to support it. Clear thinking and warm, positive feelings are not enough. Those already in favor of the idea must be willing to work out compromises and publicly supported technical and financial assistance and retribution for those whose property rights are damaged, all of which may be necessary to win acceptance. Local, state, and federal agencies must cooperate to get the largest public good for the least social and economic cost. Elected representatives of the people must provide legislation which both exercises the will of the majority and protects the rights of the minority. And local leaders and leaders of various interest groups must be brought together to find ways to either make this idea work or find a better alternative.

How do we bring about these changes in behavior? For this analysis, I shall draw upon the works of Dr. Gordon Lippitt, an outstanding psychologist, and Dr. Ralph Tyler, nationally recognized educational theorist and behavioral scientist plus my own experience and study of public policy education.

Why People Resist Change

First, let's look at Gordon Lippitt's analysis of why people resist change. In brief, he says that people resist change for the following reasons:

. . . When the purpose is not made clear—mystery and ambiguity cause suspicion and anxiety. If people can't tell where you're going, they may be reluctant to join you for the trip.

. . . When they are not involved in the planning.

. . . When an appeal is based on your personal reasons not theirs.

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. . . When their values, norms, and habits are ignored.

. . . When they don't understand something.

. . . When there is fear of failure, i.e., that the idea won't work.

. . . When the costs (social and economic) are too high in relation to the benefits or when they believe the other alternative would be better.

. . . When the present situation seems satisfactory. Why upset the applecart?

. . . When they think they may have to pay the costs for benefits someone else will receive.

Overcoming Resistance to Change

Turning this coin over and looking at it from the positive view, we have learned a great deal about how to reduce resistance to change (i.e., increasing the number of people for and reducing the number against recycling urban sludge to the land). Some of the principles are as follows:

. . . First recognize that some people are going to be directly affected. Find out their interests and concerns, what they'll likely to object to—then concentrate on meeting as many of their objectives as possible.

. . . Involve the people in the diagnostic and creative processes of decision making—they tend to understand and support what they create. People riding in the boat with you seldom drill a hole in the bottom.

. . . Allow the people to blow off steam. Too often people pushing an idea try to move ahead "so fast that the opposition won't have a chance to organize." These famous last words show lack of appreciation for the principle of "catharsis"—to relieve emotion so that objective discussion and deliberation can take place. Don't fear it! Encourage it!

. . . Be certain that people agree upon the goals and reasons for the change. Clarify the whys and wherefores.

. . . Build a trusting climate—
  . . .Tell the truth.
  . . .Maintain open communications.
  . . .Don't spring decisions on them.
  . . .Develop mutual respect.

. . . Provide the information needed for people to think intelligently. This provides the basis for people to make sound decisions.

. . . Keep people informed. They will get more intimately involved if they know the latest details on environmental quality problems and what will likely happen if we recycle urban sludge on to the land.

Our own experiences in dealing with our friends, our families, the people with whom we work, and the public lead us to these conclusions.

Helping People Acquire New Behaviors

We who wish people to change their behavior seldom can get them to do so by saying "You ought to think, feel, or act differently". Neither can we coerce them into it. What we can do is provide stimuli which hook their interests or concerns—clean water to drink, better fishing, more swimming areas. Then, they will behave differently—we hope more positively—toward recycling urban sludge to the land, we will have achieved our goal.

Now let's turn to Dr. Tyler. He adds the following to Dr. Lippitt's suggestions on how to get people to change their behavior.

. . . For a change of behavior to take place, the person must perceive a connection between what he is learning and how it affects his own life, e.g., provides a safer environment, so he's for it; or, spreads heavy metals on his land so he's against it.

. . . Change is more rapid when people get information from a variety of approaches in which they can see common elements in a variety of situations.

. . . Each idea and relationship must be within the person's ability to perceive at his level of interest, concern, and knowledge.

. . . In designing information programs, clarify the behavior you seek to develop in the individuals. With reference to recycling sludge to the land, what behavior do we wish to stimulate? Examples are:

  . . . Do the people lack interest? If so, the behavior we need to develop is "greater interest."

  . . . Do the people need to develop an attitude of concern for public welfare? If so, we need to help them see the effects of pollution on our rivers and lakes.

  . . . Are they familiar with the various methods of dealing with the problem (urban sludge in this instance)? If not, our goal should be to acquaint them with what the choices are.

  . . . Do they need greater ability to predict probable consequences of alternative methods of disposal or sludge? If yes, we need to provide them with the information on what would happen if we were to implement various alternatives (how they work, costs involved, benefits, who pays the costs, who benefits).

A PROPOSED EDUCATIONAL AND INFORMATIONAL PROGRAM

On the basis of the problem we face in winning public support for recycling urban sludge to the land and the principles of behavioral change outlined above, let me propose an Educational and Informational Program. In developing such programs, we face *five fundamental questions:*

1. *Whom specifically are we beaming the program toward?* Who are the target audiences? Different segments of society have different interest levels, differences in prior knowledge and understanding, different vested interests, and different concerns. So far greatest effect, we approach each of them in a different way. For this program, I identify *four major audiences:*
   (1) The uninterested general public.
   (2) Decision makers and others already concerned about the environment and different ways of handling urban sludge.
   (3) People with vested interests.
   (4) Professionals from government agencies and institutions who work directly with the people who will be most affected by this decision.
2. What behavioral changes do we wish to bring about in each segment?
   . . .Awareness and interest.
   . . .A decision to believe in an idea.
   . . .Active engagement in support of the idea.
   . . .Involvement in modification and innovation to put the idea into effect.

   Differentiation in interest and knowledge among various target audiences make it necessary to concentrate on behavior changes appropriate to each. Also, mass methods and media are most effective and economical for some behavioral changes, while face-to-face contact is best for other.
3. *What information is needed to capture the attention and interest of the people in each audience and to bring about the desired behavioral change?*
   It takes different information to interest the public-spirited citizen not directly involved than it does to interest an irate farmer who has his mind made up that "they're not going to dump that city sludge on my land."
   Also, it is important to figure out exactly which information is needed by the audience concerned so as not to bore people with something they already know or waste time and money trying to "teach them more than they want to need to know to change their behavior."
4. What is the best combination of educational methods for bringing about the type of change desired?

Now, from this let us put together a four part educational program, one for each target audience.

Part I. *For the general public:*

a. *Behavioral changes we seek*—greater awareness, interest, and concern about recycling urban sludge to the land.

b. *Methods*—clarify goals. Attach a new interest (recycling sludge to the land) to an old one (reducing pollution of the water). The public knows that people in cities and towns are going to continue to produce sewage and that it must be disposed of some way. They also know that it is impossible to use septic tanks and disposal fields for large concentrations of people. They know that sewage goes into sewers. Beyond that, they don't know much—nor do they care, unless sewage disposal becomes a problem—which it has.

c. *Means of communication*—news releases and feature stories in mass media (TV, radio, newspapers, magazines) and speeches.

Part 2. *For decision makers and other concerned about the environment and different ways of handling urban sludge:*

This includes lay leaders, legislators, elected officials, interest groups, and leaders of various institutions serving the public.

a. *Behavioral changes we seek*—active support for recycling sludge to the land.

b. *Methods*—broaden the peoples base of knowledge and understanding about ways of handling sludge and the consequences of each. With this knowledge people can make choices based upon their own value system, which hopefully already includes a desire for cleaning up the environment.
First, they must be given comparative knowledge about all the alternatives. Among the alternatives are:
. . . Recycling sludge to good farm land.
. . . Recycling sludge to the lakes, rivers, or ocean.
. . . Putting it on strip mined land.
. . . Other

For each alternative, we should also provide an analysis of such things as
. . . Dollar costs in terms of aggregates for a city, or per capita, or some other meaningful figure.
. . . Where the money comes from to pay the costs.
. . . Effect on the environment to which the sludge is being recycled. Include the physical, biological, human, and economic effects.
. . . Effect on human health.
. . . Other.

The simplest way to get people to look favorably upon one alternative is to let them compare it with others so that they can tell which one they favor.

This takes some courage on the part of professionals and planners—and some faith in the judgment of the public. But if we don't have that, we haven't much faith in democracy.

We in Public Policy Education call this the Problems—Alternative—Consequences approach.

c. *Means of communication*—being somewhat difficult to present, emphasis should be given to face-to-face contact where possible in lectures, symposia, forums, and seminars. People need opportunities to discuss this with experts. Carefully prepared pamphlets, leaflets, and feature stories are excellent supplements.

Part 3. *For people with vested interests which will have to be dealt with before the idea can be accepted.*

This includes legislators who must prepare legislation, public officials whose duty it is to make decisions, and citizens who will be significantly affected.

a. *Behavior changes we seek*—favorable action, reduced criticism.

b. *Methods*—include them in the formulation of decisions, working out compromises, finding better alternatives, and compensating those hurt by the decision. Even though most of this group of people has a vested interest to protect, they also know enough to realize that sludge must be disposed of some way and that ways must be found to keep the environment clean.

It should be recognized that many of these people have a positive attitude, excellent minds, and great knowledge with which to supplement the brainpower of the professionals. They are in some ways a free resource.

And there are some don'ts: (1) Don't try to sell smart people a bill of goods (2) Don't ask leaders to be a rubber stamp.

Part 4 *For the professionals from federal, state, and local government agencies and institutions who work closely and directly with the people affected by the decision:*

a. *Behavioral changes we seek*—greater knowledge, favorable attitudes, active support.

b. *Methods*—involvement. They know a great deal about the people on whom the decision will impinge and have a great deal of information at their fingertips to contribute to the educational processes necessary to win public support. And they have a desire to help.

c. *Means of communication*—personal contact, seminars in which all "agencies" are included.

In conclusion, a great deal can be accomplished with an educational and informational program to win public acceptance of recycling urban sewage and sludge to the land. In order to use our limited resources efficiently, such programs should be carefully thought through and planned carefully so that the necessary information can be developed and disseminated as quickly as possible.

We should remember that the changing of public opinion takes time. For people to acquire information and change their ways of thinking, feeling, and action is a slow process. To settle issues such as this may take 2 to 10 years.

Remember—*Leadership consists of getting people to do what you want them to do because they want to do it!*

Lippitt Gordon L., "Overcoming Human Resistance to Change," *Selected Perspectives for Community Resource Development* (North Carolina State University, Raleigh, North Carolina).

Public Affairs Education, A report of the Cooperative Extension Service Committee on Policy (Extension Service, U. S. Department of Agriculture, Washington, D. C., 1969).

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Experiences at Penn State with Land Application

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The Waste Water Renovation and Conservation Project was designed in 1962 and was put into operation in 1963. It was one of the first comprehensive research projects in the United States to investigate the feasibility of disposing of large volumes of secondary treated sewage effluent on the land by spray irrigation. From these investigations the "Living Filter" concept was evolved. The term was first used for the title of a black and white film produced in 1965 depicting some of the early results of the project. Since then, the term "Living Filter" has become more or less synonymous with the idea of spray irrigation of municipal wastewater on the land.

The idea embodied in this concept is to apply wastewater on the land in such a manner so as to utilize the entire bio system—soil, vegetation, microorganisms—as a living filter to renovate the wastewater for direct recharge to the groundwater reservoir. This can be accomplished by controlling application rates and by maintaining normal aerobic conditions within the soil. Under these conditions organic and inorganic contituents in the wastewater are removed and degraded by microorganisms, chemical precipitation, ion exchange, biological transformation, and biological absorption through the root systems of the vegetative cover. The utilization of the vegetative cover as an integral part of the system to complement the microbiological and physiochemical systems in the soil is an essential component of the living filter concept and provides for maximum renovation capacity and durability of the system.

Treated municipal sewage effluent has been spray irrigated on cropland and in forested areas for a 12-year (1963-1974) period at the Penn State Project. The results of this research will be used to illustrate some of the benefits and evils of a land application system. Forested areas irrigated consisted of a mixed hardwood forest, a red pine plantation (*Pinus resinosa*), and a sparse white spruce (*Picea slauca*) plantation established on an abandoned old field. Types of crops irrigated were wheat, oats, corn, alfalfa, red clover, and reed canarygrass. Detailed descriptions of these areas have been previously reported by Parizek et. al. (1967) and Sopper (1968, 1971). The two soil types present on the site are the Hublersburg with a surface texture ranging from silt loam to silty clay loam on slopes ranging from 3 to 12 percent and the Morrison sandy loam with slopes ranging from 3 to 20 percent.

Sewage effluent was applied in various amounts ranging from 2.5 cm per week to 15 cm per week and over various lengths of time ranging from 16 weeks during the growing season to the entire 52 weeks. Rates of application varied from 6.2 to 16 mm per hour.

CHEMICAL COMPOSITION OF MUNICIPAL SEWAGE EFFLUENT

The chemical composition of municipal effluent is illustrated in Table 1 based upon samples collected from the University treatment plant. Treatment consists of both primary and secondary treatment. Secondary treatment includes standard and high-rate trickling filters and a modified activated sludge process followed by final settling. The total amount of each constituent applied per acre year at the 5 cm per week application rate is also given in Table 1.

The fertilizer value of these wastewaters is readily evident in that the 5 cm per week application provides commercial fertilizer constituents equivalent to approximately 233 kilograms of nitrogen, 224 kilograms of phosphate (P_2O_5), and 254 kilograms of potash (K_2O). This would be equal to applying about 2200 kilograms of a 10-10-11 fertilizer annually.

Table 1. TYPICAL CHEMICAL COMPOSITION OF MUNICIPAL SEWAGE EFFLUENT

Constituent	Average Concentration	Total Amount Applied[1]
	mg/l	kg/ha
pH	8.1	—
MBAS	0.37	6
Nitrate-N	8.6	143
Organic-N	2.4	40
NH_4-N	0.9	14
P	2.651	44
Ca	25.2	420
Cl	41.3	792
Mg	12.9	215
Na	28.1	469
Fe	0.4	9
	ug/l	kg/ha
B	169	3.26
Mn	61	1.15
Cu	109	1.96
Zn	211	4.15
Cr	23	0.41
Pb	104	2.12
Cd	9	0.19
Co	62	1.24
Ni	93	1.82

[1] Total amount applied on areas which received 5 cm of effluent per week.

Agronomic Areas

Nitrogen and phosphorus are the two key eutrophic elements in municipal wastewater and therefore discussion on renovation will be limited to these two elements. The overall efficiency of the biological system to accept and renovate wastewater can be evaluated by observations on the quality of percolating water within the surface soil mantle. Suction lysimeters installed in all areas were used to obtain samples of percolating water at the 120 cm soil depth. Percolate samples were collected, whenever possible, after each weekly application of wastewater and analyzed for the same constituents as the wastewater.

Mean annual concentrations of phosphorous and nitrate-nitrogen for the agronomic areas during the period 1965 to 1973 are given in Tables 2 and 3. Mean annual phosphorus concentrations in the sewage effluent have varied from 2.5 to 10mg/1. Phosphorus concentrations in the percolating water at the 120 cm soil depth have been consistently decreased by more than 98 percent since the initiation of the project in 1963. Even when application rates were increased from 5 to 7.5 cm per week in 1972-73 the degree of renovation was essentially unchanged. The differences between the mean annual concentrations of phosphorus on the control and irrigated areas are quite small and insignificant considering that more than 13 meters of sewage effluent have been applied over the 11 years. It should also be noted that starting in year 1971 the reed canarygrass areas has been irrigated with a mixture of sewage effluent and liquid digested sludge (approximately one part of sludge slurry to eleven parts of effluent). This effluent-sludge mixture had a total phosphorus concentrations of 20 to 25 mg/1 and an orthophosphate level of 10 to 15 mg/1. These data indicate that phosphorus is not leaching out of the soil profile into the groundwater at significantly higher concentrations from the wastewater treated areas than from the control areas and that there appears to be no decreasing trend evident in terms of satisfactory phosphorus removal.

Table 2. MEAN ANNUAL CONCENTRATION OF PHOSPHOROUS IN SUCTION LYSIMETER SAMPLES COLLECTED AT THE 120-CM SOIL DEPTH IN THE CORN ROTATION PLOTS AND THE REED CANARYGRASS AREA

Year	Corn		Reed Canarygrass	
	cm per week		cm per week	
	0	5	0	5
	mg/1	mg/1	mg/1	mg/1
1965	0.032	0.022	—	—
1966	0.045	0.036	—	0.055
1967	0.039	0.054	—	0.053
1968	0.041	0.060	—	0.052
1969	0.066	0.070	—	0.035
1970	0.034	0.075	—	0.038
1971	0.048	0.061	—	0.061
1972*	0.022	0.035	0.067	0.054
1973*	0.013	0.020	0.036	0.052

*Application rate increased to 7.5 cm per week.

Table 3. MEAN ANNUAL CONCENTRATION OF NITRATE-NITROGEN IN SUCTION LYSIMETERS SAMPLES COLLECTED AT THE 120-CM SOIL DEPTH IN THE CORN ROTATION PLOTS AND THE REED CANARYGRASS AREA

Year	Corn		Reed Canarygrass	
	cm per week		cm per week	
	0	5	0	5
	mg/1	mg/1	mg/1	mg/1
1965	5.2	9.7	—	—
1966	4.7	7.0	—	3.7
1967	3.4	7.1	—	3.3
1968	4.5	9.5	—	3.1
1969	9.4	13.5	—	2.5
1970	10.3	10.9	—	2.4
1971	6.2	9.6	—	3.3
1972*	9.4	10.6	1.7	7.7
1973*	7.4	7.4	1.5	9.2

*Application rate increased to 7.5 cm per week.

Nitrate-nitrogen renovation was not as efficient on the agronomic areas. Nitrate-nitrogen concentrations were decreased below the 10 mg/1 level recommended by the Public Health Service for drinking water on the corn rotation area which received the 2.5 cm per week. treatment but not at the 5 cm per week level. At the higher application rate (5 cm) the mean annual concentration remained below the PHS limit only when grass-legume hays occupied 28 to 68 percent of the site during the period 1965 to 1968. Starting with 1969 the entire site has been planted with corn. Increases in the application rate from 5 to 7.5 cm during 1972 and 1973 did not significantly affect the degree of renovation on the corn area.

On the other hand, the 5 cm per week reed canarygrass areas has been exceptionally efficient in nitrogen removal and has consistently maintained the mean annual concentration of nitrate-nitrogen in percolating water below the 10 mg/1 limit. This area is irrigated year-around and therefore received twice as much nitrogen as the corn area. Even when application rates were increased to 7.5 cm per week during 1972 and 1973, mean annual concentrations were increased somewhat but still remained within acceptable levels.

Forested Areas

The forested areas were highly efficient in removing phosphorus (Table 4). Mean annual concentrations are slightly higher than that of the agronomic areas because there is no harvested crop and the phosphorus is continually recylced. Year-around irrigation of the forest areas on the Morrison soil at the 5 cm per week level has resulted in a substantial increase in phosphorus concentration in the soil percolate. As shown in Table 4, there has been a steady increase in comparison to the control area since the third year (1968) of operation. On the other hand, phosphorus concentrations in the irrigated forest areas on the Hublersburg soil which received lower application rates and shorter periods of irrigation (growing season irrigation period did not appear to reduce renovation efficiency.

The efficiency of forested areas to reduce nitrogen concentrations have been variable. It appears that forested areas can accept a 2.5 cm per week application of wastewater without having the mean annual concentration of nitrate-nitrogen exceed the PHS limit (Table 5). However, year-around irrigation of forests at 5 cm per week consistently resulted in no renovation. It also appears that forest ecosystems may be quite sensitive to wastewater application rates and may have a low threshold in terms of collapse in the renovation system. A 50 percent increase in the

Table 4. MEAN ANNUAL CONCENTRATION OF PHOSPHORUS IN SUCTION LYSIMETER SAMPLES COLLECTED AT THE 120-CM SOIL DEPTH IN THE FORESTED AREAS.

Year	Red Pine		Hardwood		Old Field		Hardwood	
	Hublersburg Soil		Hublersburg Soil		Hublersburg Soil		Morrison Soil	
	cm per week		cm per week		cm per week		cm per week	
	0	2.5	0	2.5	0	5	0	5
	mg/1	mg/1	mg/1	mg/1	mg/1	mg/1	mg/1	mg/1
1965	0.040	0.300	0.050	0.250	—	0.460	—	—
1966	0.043	0.134	0.037	0.043	0.030	0.140	0.059	0.042
1967	0.053	0.092	0.044	0.077	0.039	0.068	0.068	0.063
1968	0.075	0.089	0.106	0.222	0.040	0.053	0.071	0.116
1969	0.010	0.064	0.072	0.047	0.051	0.098	0.059	0.137
1970	0.065	0.076	0.033	0.143	0.042	0.114	0.051	0.209
1971	0.994	0.107	0.015	0.146	0.039	0.420	0.037	0.378
1972	0.113	0.105[1]	0.078	0.037[1]	0.074	0.200[2]	0.033	0.335
1973	0.028	0.035[1]	0.022	0.051[1]	0.042	0.096[2]	0.020	0.392

[1] Application rate increased to 3.8 cm per week.

[2] Application rate increased to 7.5 cm per week.

Table 5. MEAN ANNUAL CONCENTRATION OF NITRATE-NITROGEN IN SUCTION LYSIMETER SAMPLES COLLECTED AT THE 120-CM SOIL DEPTH IN THE FORESTED AREAS.

Year	Red Pine		Hardwood		Old Field		Hardwood	
	Hublersburg Soil		Hublersburg Soil		Hublersburg Soil		Morrison Soil	
	cm per week		cm per week		cm per week		cm per week	
	0	2.5	0	2.5	0	5	0	5
	mg/1	mg/1	mg/1	mg/1	mg/1	mg/1	mg/1	mg/1
1965	0.9	2.2	—	0.0	0.3	8.0	—	—
1966	0.1	2.1	0.1	0.2	0.1	5.0	0.1	10.6
1967	0.9	1.7	0.3	1.4	0.3	6.1	1.4	19.2
1968	0.9	2.7	0.1	8.0	0.2	3.7	0.1	25.9
1969	0.2	4.2	0.1	7.2	0.2	2.3	0.3	23.7
1970	<1	5.3	<1	5.0	<1	3.5	1.0	42.8
1971	2.6	8.3	0.5	5.8	0.5	3.8	0.8	17.6
1972	6.0	21.8[1]	14.7	23.9[1]	3.2	11.8[2]	4.7	22.9
1973	0.5	13.7[1]	3.7	13.5[1]	0.5	13.5[2]	1.3	17.3

[1] Application rate increased to 3.8 cm per week.

[2] Application rate increased to 7.5 cm per week.

application rates (2.5 to 3.8 cm and 5 to 7.5 cm) after 9 years of successful operation and renovation resulted in a complete break-through in terms of concentrations of nitrate-nitrogen in percolating water. Mean annual concentrations nearly tripled the first year (1972) and all exceeded 10 mg/1.

Table 6. MEAN ANNUAL CONCENTRATION OF NITRATE-NITROGEN IN SUCTION LYSIMETER SAMPLES COLLECTED AT THE 120-CM SOIL DEPTH IN THE RED PINE PLANTATION IRRIGATED AT 5 CM PER WEEK.

	Red Pine	
	Hublersburg Soil	
Year	cm per week	
	0	5
	mg/1	mg/1
1965	0.9	3.9
1966	0.1	9.3
1967	0.9	13.8
1968	0.9	19.9[1]
1969	0.2	24.2[2]
1970	1	8.3
1971	2.6	2.9
1972	6.0	14.5[3]
1973	0.5	9.0[3]

[1] Blowdown in November, 1968.

[2] All pine trees cut and removed.

[3] Application rate increased to 7.5 cm per week.

The Old Field area has been somewhat exceptional in comparison to the other forest areas in terms of nitrogen renovation. This area receives the highest application rate on the Hublersburg soil and yet has consistently maintained nitrate-nitrogen levels below 10 mg/1 throughout the 9 year period (1963-1971) without the harvest of any crop. In 1963 at the start of the project the area was primarily an open weed field with a few scattered spruce saplings (1 to 2 meters in height). Although the trees are now more than 7 meters in height the spruce stand is still sparse with fairly large open areas. It appears that the annual and perennial weeds which occupy these open areas during the growing season (irrigation period) provide a temporary storage for nitrogen and hence reduce nitrate-nitrogen leaching losses. In the fall, vegetative growth ceases and nitrates are again available for leaching. However, since irrigation has ceased by this time, the concentrations of nitrate-nitrogen in percolate water remains at a low level.

This same phenomena was observed in the red pine plantation which was irrigated at the 5 cm per week level. Mean annual concentrations of nitrate-nitrogen steadily increased from 1963 to 1969 (Table 6). In November, 1968 a snow storm resulted in complete blow-down of the plantation. In 1969 the area was clearcut and all trees were removed. Immediately a dense cover of herbaceous vegetation developed which was similar to that on the irrigated Old Field area. As a result the mean annual concentration of nitrate-nitrogen decreased from 24.2 mg/1 in 1969 to 8.3 mg/1 in 1970 and to 2.9 mg/1 in 1971. Subsequent increases in 1972 and 1973 were due to the increased application rate.

EFFECTS ON CHEMICAL PROPERTIES OF THE SOIL

Soil samples were taken on all areas to a depth of 150 cm in the fall after cessation of irrigation in 1963, 1967, and 1971. Soil samples were analyzed for the same constituents as was the effluent to determine if any significant concentrations of nutrients were accumulating in the irrigated areas.

The exchangeable cations (K, Ca, Mg, Na, and Mn) and boron were extracted from the soil with ammonium acetate (Jackson, 1958) and analyzed with an arc spectrometer (Baker, et. al., 1964). Exchangeable hydrogen was determined using a barium chloride buffering technique (Jackson, 1958). Organic matter was determined using a potassium dichromate-sulfuric acid oxidation method (Peech, et. al., 1947). Soil pH was measured with a glass electrode using a 1:1 soil to water mixture. Total nitrogen was analyzed using a modified Kjeldahl method to include nitrates (Jackson, 1958). The phosphorus concentration was determined by using the Bray extraction procedure (Jackson, 1958).

The results of the soil analyses for 1963 and 1971 for the two areas on each soil type which received the highest applications of effluent are given in Tables 7 and 8. These two areas were the old field 5-cm area on the Morrison soil.

Results of the soil analyses of the 1971 samples indicated that the effects of effluent irrigation on exchangeable potassium, organic matter, pH, and total nitrogen were small and inconsistent. However, there were significant changes in the concentrations of calcium, magnesium, sodium, manganese, boron, and phosphorus. Calcium, magnesium, and boron concentrations increased significantly at the 30-cm depth in both the Hublersburg and Morrison soils and in all the vegetative cover types. Sodium concentrations increased significantly at all depths in the Hublersburg and Morrison soils and in all the vegetative cover types. Manganese concentrations decreased significantly in the upper 90 cm of the Hublersburg soil on the hardwood 2.5 cm treated plot and the upper 90 cm of the Morrison soil on the new gameland hardwood 5-cm treated plot. Phosphorus concen-

Table 7. MEAN CONSTITUENT CONCENTRATIONS FOR THE OLD FIELD 5-CM AREA ON THE HUBLERSBURG SOIL TYPE

Year and Area	Depth cm	ME/100gms					PPM					
		K	Ca	Mg	Na	H	Mn	B	P	pH	%N	%OM
1963 Control	30	0.40	1.43	0.27	0.10	11.84	71.60	0.53	8.70	4.79	0.088	2.147
	60	0.47	2.00	0.83	0.17	8.67	20.46	0.60	0.76	5.23	0.016	0.370
	90	0.47	1.13	1.27	0.20	9.33	23.46	0.53	0.38	4.91	0.012	0.167
	120	0.43	0.93	1.57	0.20	—	18.60	0.53	0.38	—	0.010	—
	150	0.47	0.97	1.53	0.13	—	18.13	0.53	0.38	—	0.010	—
1963 Treatment	30	0.63	1.73	0.50	0.23	16.06	44.60	1.00	16.05	4.96	0.072	2.407
	60	0.60	1.87	0.90	0.20	18.74	20.80	0.80	1.48	4.68	0.022	0.390
	90	0.63	1.03	1.00	0.10	11.48	26.00	0.86	0.71	4.45	0.019	0.183
	120	0.53	0.77	0.97	0.10	—	62.00	0.80	0.00	—	0.014	—
	150	0.47	0.57	0.77	0.10	—	17.93	0.80	0.00	—	0.016	—
1971 Control	30	0.10	2.00	0.23	0.23	14.91	15.86	0.06	10.95	5.06	0.082	2.683
	60	0.03	2.16	0.80	0.23	11.56	12.13	0.06	0.91	4.89	0.016	0.313
	90	0.00	1.80	1.43	0.23	12.05	10.60	0.00	1.00	4.84	0.009	0.167
	120	0.03	1.53	1.63	0.20	—	9.46	0.06	0.90	—	0.005	—
	150	0.00	1.16	1.50	0.20	—	8.66	0.00	1.78	—	0.005	—
1971 Treatment	30	0.43	3.33	1.73	0.33	15.52	14.53	0.60	50.80	5.42	0.095	2.300
	60	0.20	2.00	1.33	0.30	16.36	17.20	0.20	3.48	4.99	0.026	0.343
	90	0.06	1.40	1.23	0.33	16.68	15.80	0.06	1.90	4.82	0.017	0.190
	120	0.16	1.00	1.36	0.30	—	15.66	0.06	1.66	—	0.020	—
	150	0.13	1.00	1.43	0.33	—	16.06	0.13	1.76	—	0.028	—

Table 8. MEAN CONSTITUENT CONCENTRATIONS FOR THE HARDWOOD 5-CM AREA ON THE MORRISON SOIL TYPE

Year and Area	Depth cm	ME/100gms					PPM					
		K	Ca	Mg	Na	H	Mn	B	P	pH	%N	%OM
1967 Control	30	0.16	0.90	0.10	0.16	13.43	55.93	0.26	16.50	4.55	—	2.210
	60	0.16	0.70	0.33	0.16	12.07	16.46	0.13	2.13	4.67	—	0.547
	90	0.16	0.46	0.33	0.20	10.38	10.46	0.13	1.23	4.76	—	0.223
	120	0.26	0.43	0.53	0.20	—	4.80	0.33	0.83	—	—	—
	150	0.06	0.36	0.56	0.20	—	10.13	0.06	0.88	—	—	—
1967 Treatment	30	0.13	1.36	0.40	0.23	12.94	19.93	0.26	75.55	5.50	—	1.240
	60	0.06	0.50	0.30	0.23	10.76	11.86	0.00	4.90	4.99	—	0.560
	90	0.13	0.46	0.36	0.23	13.37	19.20	0.13	2.18	4.94	—	0.350
	120	0.16	0.60	0.36	0.20	—	16.26	0.13	1.92	—	—	—
	150	0.26	1.46	1.10	0.26	—	15.33	0.20	1.50	—	—	—
1971 Control	30	0.00	0.53	0.10	0.20	13.72	32.73	0.06	6.25	4.96	0.109	2.867
	60	0.16	1.13	0.80	0.20	13.36	11.00	0.20	3.16	4.97	0.036	0.300
	90	0.26	0.76	1.03	0.20	11.54	10.86	0.26	0.66	4.99	0.028	0.230
	120	0.20	0.53	0.83	0.20	—	9.86	0.20	1.06	—	0.023	—
	150	0.00	0.50	0.96	0.16	—	7.26	0.00	0.68	—	0.016	—
1971 Treatment	30	0.06	1.86	0.53	0.23	7.35	4.13	0.13	143.75	6.15	0.084	1.483
	60	0.03	0.96	0.36	0.20	5.20	4.93	0.20	31.60	5.51	0.052	0.413
	90	0.10	1.30	0.73	0.20	9.34	5.73	0.13	9.95	5.06	0.037	0.243
	120	0.03	1.10	0.83	0.23	—	6.40	0.06	1.98	—	0.032	—
	150	0.13	0.73	0.80	0.23	—	4.20	0.20	0.98	—	0.032	—

trations increased significantly in the Hublersburg soil in the 30-cm depth of the hardwood 2.5 cm plot, the upper 60 cm of the old fields 5-cm and red pine 2.5 cm plots. Phosphorus also increased significantly in the upper 150 cm of the Morrison soil on the new gameland hardwood 5-cm plot.

Of the 11 constituents analyzed, only potassium, sodium, manganese, exchangeable hydrogen, boron, and phosphorus had significant changes over time. Potassium concentrations decreased in all five depths of the treated and control plots in the Hublersburg soil on the old field 5-cm plots. Sodium concentrations increased significantly in all five depths of the Hublersburg soil in the old field 5-cm treated plot, the 60 and 90 cm depths of the hardwood 2.5-cm treated plot, and the lower 90 cm of the red pine 2.5-cm treated plots. Manganese concentrations decreased significantly in all five depths on both soil types and in all vegetation cover types. Exchangeable hydrogen concentrations decreased significantly in the upper 90 cm of the Morrison soil on the new gameland hardwood 5-cm treated plot. Boron decreased significantly in all five depths of the Hublersburg soil on the old field 5-cm and red pine 2.5-cm treated plots. Phosphorus increased significantly in the 30 cm of the Hublersburg soil on the hardwood 2.5-cm and red pine 2.5-cm treated plots, and in the upper 90 cm of the Hublersburg soil on the old field 5-cm and the Morrison soil on the new gameland hardwood 5-cm treated plots.

CROP RESPONSES

Yields

During the initial years of the project a variety of crops were tested. Average annual crop yields during the period 1963 to 1970 have previously been reported by Sopper and Kardos (1973). Since 1968 the two primary crops grown have been silage corn and reed canarygrass. Our experience has shown that these two crops are the best suited to our site and are the most efficient in terms of nutrient utilization. During the past 12 years the crop areas irrigated with 5 cm of effluent weekly have received a total of approximately 20 meters of wastewater. During this period annual yield increases have ranged from 0 to 350 percent for corn grain, 5 to 130 percent for corn silage, 85 to 190 percent for red clover, and 79 to 140 percent for alfalfa.

Nutrient Composition

Under the "living filter" concept the vegetative cover is an integral part of the system and should complement the microbiological and physiochemical activities occurring within the soil to renovate the effluent by removal and utilization of the nutrients applied. The crops harvested from the irrigated areas are usually higher in nitrogen and phosphorus than the control crops, however, the differences are not large. This is partially due to the fact that the control areas receives a normal application of commercial fertilizer each year—equal to about 900 kilograms of a 10-10-10 fertilizer per hectare annually.

Nutrients Removed by Crop Harvest

The contribution of the higher plants as renovators of the wastewater is readily evident when one considers the quantities of nutrients, expressed in kilograms per hectare, removed in crop harvest. Such data indicate that the vegetative cover can contribute substantially to the durability of a "living filter" system particularly where a crop is harvested and utilized. At the 5-cm per-week level of effluent irrigation the harvest of corn silage removes about 179 kilograms of nitrogen and 48 kilograms of phosphorus. Reed canarygrass, which is a perennial grass, is even more efficient in that it removes about 457 kilograms of nitrogen and 63 kilograms of phosphorus. The difference is primarily due to the fact that the grass is already established and actively growing in early spring even before the corn is planted.

The amounts of nutrients removed annually vary with the amount of wastewater applied, amount of rainfall, length of the growing season, and the number of cuttings of the reed canarygrass, which is perennial grass, is even more efficient in that it removes about 457 kilograms of nitrogen and 63 kilograms of phosphorus. The difference is primarily due to the fact that the grass is already established and actively growing in early spring even before the corn is planted.

The amounts of nutrients removed annually vary with the amount of wastewater applied, amount of rainfall, length of the growing season, and the number of cuttings of the reed canarygrass.

The efficiency of crops as renovating agents can be assessed by computing a "removal efficienty" expressed as the ratio of the weight of the nutrient removed in the harvested crop to the same nutrient applied in the wastewater. Average renovation efficiencies for the silage corn and the reed canarygrass crops are given in Table 9. At the 2.5-cm per week level of application of wastewater, the corn silage removes nutrients equivalent to about 334 percent of the total applied nitrogen, 230 percent of the applied phosphorus, and 280 percent of the applied potassium. At the 5-cm per week level, the corn silage removed more than 100 percent of the applied nitrogen, phosphorus, and potassium.

Similarly harvest of reed canarygrass removes on the average about 373 kilograms of nitrogen and about 50 kilograms of phosphorus. These removals are equivalent to renovation efficiencies of 122 and 63 percent, respectively.

Table 9. AVERAGE RENOVATION EFFICIENCY OF THE SILAGE CORN AND REED CANARYGRASS CROPS

Nutrient	Variety and amount of effluent applied		
	Corn Silage Pa. 602-A		Reed canarygrass
	1	2	2
	%	%	%
Nitrogen	334	145	122
Phosphorus	230	143	63
Potassium	280	130	117
Calcium	38	15	9
Magnesium	53	27	19
Chloride	26	14	20
Sodium	2	1	1
Boron	10	4	2

TREE GROWTH RESPONSES

Red Pine - Experimental plots were established in a red pine plantation in 1963. These plots have been irrigated with sewage effluent during the past 12 years at rates of 2.5 cm and 5 cm per week during the growing season (April to November). The plantation was established in 1939 with the trees planted at a spacing of 2.5 by 2.5 meters. In 1963 the average tree diameter at breast height was 22 cm and average height was 11 meters.

Diameter and height growth measurements were made annually. Average annual height growth on the 2.5-cm per week plot was 58 cm in comparison to 42 cm on the control plot. On the plot receiving 5 cm per week, height growth continually decreased up to 1968 when high winds following a wet snowfall completely felled every tree on the plot.

Increment cores were taken from sample trees in all areas to determine average annual diameter growth. Irrigation at the 2.5-cm per week level resulted in an average annual diameter growth of 4.3 mm in comparison to 1.5 mm on the control, an increase of 186 percent.

White Spruce - Two experimental plots were established in a sparse white spruce plantation on an abandoned old-field area. The trees in 1963 ranged from 0.9 to 2.5 meters in height. One plot has been irrigated with sewage effluent during the past 12 years at the rate of 5 cm per week, while the second plot has been maintained as a control.

Average height of the trees on the irrigated plot in 1974 was 7.5 meters and ranged from 5.5 to 9.5 meters. The average height of the trees on the control plot was 3.1 meters and ranged from 2.7 to 4.8 meters. Over the 12-year period average annual height growth was 60 cm on the irrigated areas and 25 cm on the control areas, representing a 140 percent increase as a result of sewage effluent irrigation.

Average diameter of trees on the irrigated plot was 9.5 cm in comparison to 3.6 cm on the control plot. Measurements taken from increment cores indicated that the average annual diameter growth on the irrigated trees was 10 mm and on the control trees 4.5 mm representing a 122 percent increase.

Mixed Hardwoods - A hardwood forest, consisting primarily of oak species, was irrigated with sewage effluent at 2.5 cm per week during the growing season and at 10 cm per week for the entire year (52 weeks).

Average annual diameter growth during the 1963 to 1974 period is given in Table 10. Application at 2.5 cm per week produced only a slight increase in diameter growth; however, the 5-cm per week level resulted in an 80 percent increase. These values pertain primarily to the oak species. Some of the other hardwood species present on the plots have responded to a greater extent. For instance, increment core measurements made on red maple *(A. rubrum)* and sugar maple *(A. saccharum)*, indicate that the average annual diameter growth during the past 12 years has been 13 mm on the trees irrigated with 2.5 cm of effluent per week in comparison to 2.6 mm on control trees, a 400 percent increase in average annual diameter growth.

Table 10. AVERAGE ANNUAL DIAMETER GROWTH IN HARDWOOD FORESTS IRRIGATED WITH SEWAGE EFFLUENT

Weekly Irrigation Amount	Average Diameter Growth	
	Control	Irrigated
cm	mm	mm
2.5[1]	4.1	4.8
5[2]	3.3	6.0

[1] Irrigated with 2.5 cm of sewage effluent weekly during growing season from 1963 to 1974.

[2] Irrigated with 5 cm of sewage effluent weekly during the entire year from 1965 to 1974.

RENOVATION EFFICIENCY OF FORESTS

The nutrient element content of the foliage of the vegetation on the irrigated plots was consistently higher than that of the vegetation on the control plots. It is therefore obvious that the forest vegetation is contributing to the renovation of the percolating effluent; however, its order of magnitude is difficult to estimate because the annual storage of nutrients in the woody tissue and the extent of recycling of nutrients in the forest litter are extremely difficult to measure. Although considerable amounts of nutrients may be taken up by trees during the growing season, many of these nutrients are redeposited annually in leaf and needle litter rather than being hauled away as in the case of harvested agronomic crops.

A comparison between the annual uptake of nutrients by an agronomic crop (silage corn) and a hardwood forest is given in Table 11. It is obvious that trees are not as efficient renovation agents as

Table 11. ANNUAL UPTAKE OF NUTRIENTS BY A SILAGE CORN CROP AND A HARDWOOD FOREST IRRIGATED WITH 5 CM OF EFFLUENT WEEKLY

Nutrient	Corn Silage Pa. 602-A	Renovation Efficiency[1]	Hardwood Forest	Renovation Efficiency
	kg/ha	%	kg/ha	%
N	180	145	94	39
P	47	143	9	19
K	144	130	29	22
Ca	30	15	25	9
Mg	26	27	6	4

[1] Percentage of the element applied in the sewage effluent that is utilized and removed by the vegetation.

agronomic crops. Whereas harvesting a corn silage crop removed 145 percent of the nitrogen applied in the sewage effluent, the trees only removed 39 percent most of which is returned to the soil by leaf fall. Similarly only 19 percent of the phosphorus applied in the sewage effluent is taken up by trees in comparison to 143 percent of the corn silage crop.

WOOD FIBER QUALITY

The results of a recent study by Murphey *et. al.* (1973) provides some insight as to effects of municipal wastewater irrigation on the anatomical and physical properties of the wood of forest trees. Wood samples were collected from red pine and red oak trees irrigated with sewage effluent.

They reported that sewage effluent irrigation on red pine resulted generally in increased specific gravity, increased tracheid diameter, decreased cell wall thickness, and no change in tracheid length. Likewise changes also occurred in red oak wood due to irrigation with sewage effluent. They reported a five percent reduction in the early wood vessel segment diameter. These large barrel-shaped elements are the causes of "picking"—the lifting of the surface of paper during printing. The smaller, longer cells produced by effluent irrigation might reduce this problem when using ring porous woods such as red oak for pulp. An increase of wood volume occupied by the broad rays from nine percent in the untreated xylem to 11.5 percent of the wood developed during irrigation. The increase in number and height of broad rays would cause an increase in the percentage of "fines" in a pulp mix. Increase in specific gravity and particularly in the change in the amount of latewood from about one-half to three-quarters of the growth ring provides more mass of fibers per unit volume. Coupled with the growth rate change, irrigation with municipal wastewater results in the development of more fiber per treated tree. The increase in fiber and vessel segment length also increased the utility of this wood for pulp. Murphey *et. al.* (1973) concluded that in general the alterations of the wood fibers resulting from wastewater irrigation enhanced their utilization as a raw material for pulp and paper.

ECOSYSTEM STABILITY

Ecosystems are somewhat elastic and can withstand a certain amount of stress prior to permanent change or collapse. Weekly application of wastewater will certainly impose a stress on the ecosystem. An unresolved question is whether the impact will be sufficient to cause a significant change and whether the change will be desirable or undesirable. Regular applications of large volumes of wastewater can turn a relatively dry site into a moist super-humid site and a relatively sterile site into a fertile one. Such changes may influence species composition and plant density on the site as well as fungi, bacteria, and microorganism types and populations. These changes, in turn, may influence the habitat and utilization of the site by wildlife. In general these changes are subtle and occur over a long period of time. Since there are no municipal wastewater spray irrigation projects in the United States older than 12 years on which the ecosystems have been monitored annually, we can only conjecture the long term effects. Results from the Penn State Project will illustrate some of the trends observed during the past 12 years.

Forest Reproduction

Forest reproduction was tallied on milacre plots in a mature mixed hardwood forest which was irrigated with sewage effluent at the rate of 2.5 cm per week during the growing season. Results indicated a drastic reduction in the number of tree seedlings present in the irrigated area. A pre-irrigation survey indicated about 39,000 tree seedlings per hectare in the control area and about 35,800 tree seedlings per hectare in the area to be irrigated. After 10 years of irrigation, remeasurement indicated only 4520 seedlings per hectare were present in the treated area. A similar reduction was also found in the number of herbaceous plants in the irrigated forest area. The initial survey indicated about 213,200 stems per hectare, whereas 10 years later there were only 36,500 stems per hectare.

Forest Floor

Measurements of the forest floor (leaf litter) made the summer of 1974 indicate that drastic changes have occurred in relation to the accumulation and decomposition of the forest floor. For instance, in the hardwood forest on the Morrison soil which receives the 5 cm per week application rate the average depth of the forest floor in the irrigated area was 1.5 mm in comparison to 20 mm in the control area. Forest floor accumulations calculated on a dry-weight basis were 1206 kg/ha in the irrigated forest and 7566 in the control forest. Similar reductions in the amount of forest floor present were observed in all irrigated forest areas.

This accelerated decomposition of the forest floor may in time have detrimental effects on the physical properties of the soil. Without the protective leaf litter cover, the surface soil is more exposed to raindrop compaction which in turn might affect infiltration capacity. However, more important is the fact that the forest floor insulates the surface soil during the winter and prevents the formation of concrete frost. Without the thick forest floor cover, the exposed mineral soil is more susceptible to freezing which might result in surface runoff and overland flow during winter irrigation periods.

Preliminary observations have also indicated that changes have occurred in soil invertebrate populations (earthworms, mites, spring-tails) and in the infiltration capacity and percolation capacity of the one-foot soil depth. These investigations are continuing and complete results will be reported at a later date.

Old Field Herbaceous Vegetation

An old field area consisting primarily of poverty grass *(Danthonia spicata)*, goldenrod *Solidago spp.)* and dewberry *(Rubus Flagellaris)* was irrigated with sewage effluent at the rate of 5 cm per week during the growing season since 1963. Significant changes have been observed in species composition, vegetation density, height growth, dry matter production, percentage areal cover, and nutrient utilization. Average dry matter production was 6111 kilograms per hectare on the irrigated plot and 2027 kilograms per hectare on the control plot. This represents an average annual increase of 201 percent. Annual increases ranged from 100 to 350 percent.

Several species which were predominant prior to wastewater irrigation have been drastically reduced in number or have disappeared completely. For instance, goldenrod *(Solidago spp.)* which had 383,000 stems per hectare in 1963 has been reduced to about 33,600 stems per hectare. White Aster *(Aster pilosus)* which had about 303,700 stems per hectare in 1963 is no longer present on the site. The predominant species on the irrigated plot is clearweed *(Pilea pumila L.)* which covers more than 80 percent of the plot with approximately 47 million stems per hectare. This species is typical of shaded moist sites.

WILDLIFE HABITAT

Wildlife studies were initiated on the Penn State Project in 1971 and, hence, the results obtained to date are largely inconclusive. Wood *et. al.* (1973) reported that spray irrigation of sewage effluent at the rate of 5 cm per week in forests and on brushland appeared to have a favorable influence in the nutritive value of rabbit and deer forage. Foliar analysis of forage species indicated that crude protein, P, K, and Mg contents all increased, whereas Ca content was decreased.

Studies using the lead deer technique to determine preference for or avoidance of irrigated areas indicated that the deer used treated sites as readily as untreated sites. During the winter period, observations indicated that wild deer used the irrigated areas for resting and feeding even though these areas were often ice covered as a result of winter irrigation.

No conclusive evidence was obtained on the effects of spray irrigation on rabbit reproduction. However, they did find that the winter carrying capacity of the irrigated sites exceeded that of the control areas presumably due to the higher levels of available nutrition and improved cover conditions: Rabbits trapped on the irrigated areas appeared to be larger and healthier than those on the control area which were as much as a third lighter in weight and showed obvious signs of emaciation.

Since public hunting areas and public gamelands are potential disposal areas, some concern has been expressed by sportsmen on the possible effects on game bird reproduction. It is well known that wet spring season periods may have an adverse effect on the survival of young broods of wild turkey and grouse. Many of the young chicks die of pneumonia during these cool, wet periods. An unanswered question is whether weekly spray irrigation of wastewater will produce the same condition.

TREE MORTALIY

In 1972 a survey was made in the hardwood forest area on the Morrison sandy loam soil to determine the effect of sewage effluent irrigation on mortality. This area was selected since it is the largest (approx. 8 hectares) forest stand under irrigation. Mortality was defined as all standing dead trees. The forest stand had received 10 cm of sewage effluent weekly during the growing season only from 1964 to 1967; during the dormant season only from 1968 to 1971; and 5 cm of effluent weekly during the growing season in 1972. The results of the survey are given in Table 12. Results indicated that mortality was about 20 percent higher in the effluent-irrigated forest area. There was also a large difference in the number of living trees per hectare, particularly, in the 5 cm diameter class. Unirrigated forest areas averaged 716 trees per hectare in the 5 cm diameter class compared to only 173 trees per hectare in the irrigated forest areas.

Although many of these young saplings are lost through natural suppression, a considerable number are lost in the irrigated areas through ice breakage during winter irrigation. The survey results indicated that approximately 128 stems per hectare showed visible ice damage in the irrigated areas in comparison to 18 stems per hectare in the control areas. Seventy-five percent of these trees were in the 5 cm diameter class

Table 12. **POPULATION AND MORTALITY IN FORESTED STANDS IN CONTROL PLOTS AND IRRIGATED WITH SEWAGE EFFLUENT**

Diameter class	Living trees		Mortality	
	Irrigated	Control	Irrigated	Control
cm	stems per hectare		stems per hectare	
5	173	716	136	104
10	247	271	67	79
15	99	198	49	12
20	148	198	6	6
25	99	123	—	—
30	74	62	—	—
35	5	17	—	—
40	12	—	—	—
Total	857	1585	258	213

and the remainder in the 10 cm diameter class. The species most susceptible to ice damage was red maple. A reasonable amount of ice damage must be expected if disposal systems are to operate throughout the year. However, ice damage can be minimized through the proper design of the spray-irrigation system and the use of low-trajectory rotating sprinklers (Parizek *et. al.* 1967; Myers, 1973).

A comparison of the results of the 1972 survey made in the effluent-irrigated forest areas with the results of several other forest surveys of mixed hardwood stands on a variety of sites in central Pennsylvania indicate that 10 years of effluent irrigation have produced no great differences. The average number of living trees, 13 cm in diameter and greater, in the effluent-irrigated forests was 437 stems per hectare in comparison to an average of 382 stems per hectare in several natural mixed hardwood stands. Mortality of trees, 13 cm in diameter and greater, in the effluent-irrigated forests was 55 stems per hectare in comparison to an average 52 stems per hectare in several natural mixed hardwood stands.

GROUNDWATER RECHARGE

The amount of renovated effluent recharged to the groundwater reservoir was estimated from data available on the total amount to effluent and rainfall received by the plots, and potential evapotranspiration. Annual recharge ranged from 1.1 to 1.8 million gallons per acre irrigated with an average of 1.6 million gallons. Recharge amounted to approximately 90 percent of the effluent applied at the 2 inches per week rate. Hence it is evident that with properly programmed application, sewage effluent can be satisfactorily renovated and considerable amounts of high quality water recharged to the groundwater reservoir. In time, contributions to the groundwater of this magnitude will certainly have a beneficial effect on the local water table level.

MANAGEMENT PROBLEMS

Utilization of forests on the spray irrigation site generally necessitates the use of a solid-set irrigation system which may cause some problems. Three potential problems that may be encountered with effluent irrigation in forested areas are (1) ice damage, (2) windthrow, and (3) bark damage by sprinkler spray. The ice breakage problem has already been discussed. Bark damage by sprinkler spray can be avoided if sprinkler nozzle pressures are operated at or less than 55 p.s.i. Nozzle pressures for the solid set system used in the forests on the Penn State project are approximately 50 p.s.i. Little tree damage has been observed even on small trees within a 1 meter radius of the sprinkler head.

Windthrow of individual trees and large numbers of trees (the 0.4 hectare red pine plot irrigated with 5 cm of effluent weekly) has been the greatest problem. Weekly irrigation of sewage effluent at rates of 2.5 and 5 cm per week keep the soil moisture status near field capacity and hence encourages the development of shallow tree root systems. In November of 1968, following a weekly application of 5 cm of sewage effluent, a heavy snowfall accompanied by strong winds resulted in the complete blow down of the 0.4 hectare plot. Since then several individual trees have also been windthrown in the mixed hardwood forests. Most of the trees have been adjacent to natural forest openings, agricultural fields, roads, or power line rights-of-way. It appears that this problem could be mimimized if an unirrigated buffer zone 15 to 35 meters wide were left on the windward side of any irrigated forest area. This buffer zone would provide a wind break against prevailing winds.

REFORESTATION AND RECLAMATION

In contrast to the utilization of an existing forest for spray irrigation, there is also the option of using municipal wastewater for reforestation and reclamation of drastically disturbed areas such as those resulting from strip mining operations.

In 1968 a feasibility project was initiated to determine if municipal sewage effluent and liquid digested sludge could be used to ameliorate the harsh site conditions existing on many bituminous coal strip mining spoil banks. Revegetation of many of these banks has been unsuccessful because of high acidity, toxic levels of iron, aluminum, and manganese, low fertility, low moisture content, and extremly high summer surface temperatures.

Treatment with sewage effluent and liquid digested sludge might ameliorate these conditions. The slightly alkaline, nutrient-enriched wastewater might leach acids and toxicants below plant rooting depth and at the same time provide organic colloids to detoxify the soluble iron, aluminum, and manganese. The addition of the wastewater would also provide the necessary moisture for vegetation survival and growth and evaporational cooling should moderate the lethal surface temperatures.

To test this hypothesis spoil material was obtained from a bank over the lower Kittanning bituminous coal seam in Clearfield County, Pennsylvania. This bank was selected because it has remained barren for 23 years despite several attempts at revegetation and is extremely acid (pH 2.0 to 3.0). Approximately 25 metric tons of spoil material were placed in each of ten large boxes - 9.7 meters long, 1.2 meters wide, and 1.2 meters deep — with an open bottom having 15 cm of sand resting on natural soil. The boxes were filled with 1 meter of spoil material. Each box was planted with seven species of tree seedlings — Japanese larch, white spruce, Norway spruce, white pine, European alder, hybrid poplar, and black locust. In addition, two species of grass (orchard grass and tall fescue) and two species of legumes (crownvetch and birds-foot trefoil) were broadcast seeded in each box.

Two of the boxes were untreated and maintained as controls. The remaining eight boxes were divided into four groups of two boxes for treatment. The four treatments applied were: (1) 5 cm of sewage effluent a week, (2) 2.5 cm each of sewage effluent and sludge per week, (3) 5 cm each of sewage effluent and sludge per week, and (4) 5 cm of sludge per week. Irrigation treatments were applied for 24 weeks during the growing season.

On the unirrigated control boxes there was complete mortality of all planted seedlings and none of the grass or legume seed germinated. Vegetation in the treated boxes responded dramatically. Some of the tree seedlings survived on all treated boxes. Best overall tree seedling survival percentages were obtained on the boxes which received 5 cm of effluent per week. Under this treatment survival percentages were 65 percent for black locust, 63 percent for white pine, 40 percent for white spruce, 38 percent for European alder, 35 percent for Norway spruce, 10 percent for hybrid poplar, and 3 percent for Japanese larch. Black locust had the highest survival percentages over all treatments ranging from 65 to 85 percent. Black locust had the best height growth of surviving species and ranged from 10 to 35 cm although some individual trees attained a height of 1.2 meters. Hybrid poplar ranked second in average height growth.

Treatments were very effective in establishing a ground cover of grasses and legumes. Growth response of each species was measured in terms of pounds of dry matter produced per hectare and percentage of ground cover. Best germination and growth was obtained with the combination, 5 cm of effluent and 5 cm of sludge per week, treatment. Orchard grass and tall fescue had the highest dry matter yields of 3625 and 2963 kilograms per hectare, respectively. It was quite apparent from the results that sludge is a necessary prerequisite to the establishment of grasses and legumes from seed. The organic residue in the sludge provides the necessary seed bed for germination.

The percentage cover of the spoil material by the grasses and legumes on the irrigation treatments ranged from 28 to 100 percent for orchard grass, 5 to 91 percent for tall fescue, 3 to 56 percent for birdsfoot trefoil, and 2 to 58 percent for crownvetch. The maximum cover was obtained for all species with the combination, 5 cm of effluent and 5 cm of sludge per week, treatment. Establishment of a complete ground cover of vegetation is highly desirable since it can result in earlier stabilization and reduction of erosion, in earlier mitigation of acid drainage by diminishing net recharge through increased evapotranspiration losses, and in the acceleration of inputs of organic residues for detoxifying the soluble iron, aluminum, and manganese.

In 1972 this study was expanded to evaluate more grass and legume species. Additional boxes were constructed and filled with spoil material from the same bank as the previous study. Each box was divided into eight 120 by 120 cm foot plots. These plots were then randomly seeded with 8 species of grasses (Garrison creeping foxtail, Saratoga smoothbrome, reed canarygrass, Blackwell switchgrass, weeping lovegrass, redtop, deertongue, and climax timothy) and 8 species of legumes (sericea lespedeza, Chemung crownvetch, lathro flatpea, Iroquois alfalfa, Pennscott red clover, sweet clover, Ladino clover, and Arnot bristly locust). The boxes were irrigated for 18 weeks during the growing season with the same combination treatments (1E + 1S, 2E + 2S) used in the previous study.

The results indicated that treatment ameliorated the harsh site conditions and greatly facilitated establishment of the grasses and legumes. The grasses did much better than the legumes in both dry matter production and percent areal cover of the spoil. Weeping lovegrass and Blackwell switchgrass gave the best growth response of the grasses with 12,395 and 5,252 kilograms of dry matter per hectare, respectively, with the 2E + 2S treatment. Bristly black locust gave the best growth of the legumes with 2,029 kilograms per hectare averaged over both treatment rates. Weeping lovegrass, Blackwell switchgrass, reed canarygrass and deertongue gave the best percentage cover of the spoil with 100, 100, 100 and 96 percent areal cover respectively on the 2E + 2S treatment. Ladino clover (99), bristly blacklocust (90), Iroquois alfalfa (90), sericea lespedeza (90), and sweet clover (90) also gave good cover on the 2E + 2S treatment. These species would be the best suited for use in spoil bank stabilization and erosion control.

Dry Sludge

In 1974 a second project was initiated to investigate the feasibility of using dry sludge to revegetate a burned anthracite refuse bank located in Scranton, Pennsylvania. Heat-dried sludge was obtained from the Scranton-Dunmore treatment plant and was applied on three experimental plots established on the bank. Application rates were 0, 40, 75 and 150 dry metric tons per hectare. After spreading the sludge was incorporated with a tractor and cultivator.

The main plots were then planted with seedlings of ten tree species (red pine, white pine, Austrian pine, Virginia pine, white spruce, Japanese larch, hybrid poplar, European alder, black walnut and black locust). Subplots were broadcast seeded with five grass species (Blackwell switchgrass, deertongue, reed canarygrass, tall fescue and orchardgrass) and five legume species (bristly locust, Iroquois alfalfa, ladino clover, Penngift crownvetch, and birdsfoot trefoil). One of the main plots was maintained as a control while an irrigation system was used to irrigate the other two plots on a bi-weekly schedule during the growing system. One plot received 5 cm of city water bi-weekly and the other plot received 5 cm of treated sewage effluent.

Preliminary results indicated that tree mortality was the highest on the control plot. Best overall tree survival was obtained with the 40 tons per hectare sludge application rate. Average total height of surviving tree seedlings is given in Table 13. Species which had the greatest first-year height growth were black locust, hybrid poplar, and European alder.

Sludge applications also greatly enhanced germination and growth of the seeded grasses and legumes. In addition, a considerable amount of volunteer vegetation invaded the sludge treated plots. The average areal cover percentage of all vegetation (seeded species plus volunteer vegetation) is given in Table 14. The best vegetation establishment was obtained on the plots treated with 40 and 75 tons of dry sludge per hectare.

These results, although only preliminary, indicate that reclamation of refuse banks can be facilitated with the use of municipal sludge.

Table 13. AVERAGE TOTAL HEIGHT OF SURVIVING TREE SEEDLINGS IN CENTIMETERS

Tree Species	Sludge Application Rate — Dry Tons Per Hectare											
	0			40			75			150		
	C	W	E	C	W	E	C	W	E	C	W	E
White Pine	12	12	11	11	12	12	12	10	10	15	10	12
Austrian Pine	14	15	14	12	14	14	15	14	15	10	13	19
Virginia Pine	17	19	18	19	18	17	19	18	16	—	15	17
Red Pine	10	12	12	10	10	10	12	10	9	—	10	9
White Spruce	25	22	24	19	21	25	18	24	29	21	22	25
Japanese Larch	27	25	27	29	28	28	26	26	24	—	27	27
European Alder	41	42	42	42	44	48	38	58	59	19	59	48
Hybrid Poplar	41	31	29	80	75	48	96	95	54	69	95	76
Black Locust	64	57	55	83	76	70	78	94	102	55	83	83

C - Control
W - Water - 5 cm bi-weekly
E - Effluent - 5 cm bi-weekly

Table 14. AVERAGE AREAL COVER PERCENTAGE OF ALL VEGETATION ON THE PLOTS

Species Seeded	Sludge Application Rate — Dry Tons Per Hectare											
	0			40			75			150		
	C	W	E	C	W	E	C	W	E	C	W	E
Blackwell Switchgrass	14	47	72	10	85	91	15	90	98	5	22	13
Deertongue	22	63	75	11	87	95	11	92	100	9	68	23
Reed Canarygrass	38	70	85	63	97	100	53	100	100	50	95	98
Orchardgrass	52	88	82	65	100	100	45	100	100	45	92	100
Tall Fescue	55	73	80	60	98	100	57	100	100	25	93	98
Bristly Locust	63	60	78	25	93	98	32	92	100	8	90	88
Iroquois Alfalfa	45	95	95	30	98	98	20	100	100	10	90	92
Ladino Clover	52	97	98	37	97	100	28	100	100	18	97	98
Pennsift Crownvetch	25	88	93	42	97	99	53	100	100	37	95	98
Birdsfoot Trefoil	47	98	100	47	100	100	40	100	100	13	93	98

Sludge Treatment

C - Control
W - Water, 5 cm bi-weekly
E - Effluent, 5 cm bi-weekly

CONCLUSIONS

Twelve years of research have indicated that the living filter system for renovation and conservation of municipal wastewater is feasible and that the combinations of agronomic and forested areas provide the greatest flexibility in operation. Such a system is more adaptable to small cities and surburbs than to large metropolitan areas because of the availability of open land close to the wastewater treatment plant, although the land area requirement is not a major prohibitive factor. At the recommended level of irrigation, 5 cm per week, only 52 hectares of land would be required to dispose of 4 million liters of wastewater per day. Although large contiguous blocks of agricultural and natural forest land would be the most desirable for efficiency and economy, major metropolitan areas could utilize golf courses, playing fields, forest preserves and parks, greenbelts, scenic parkways, and perhaps even divided highway and beltway medial strips. Results also indicate that municipal wastewaters might be used to reclaim and revegetate many of the barren bituminous strip mined spoil banks and anthracite refuse banks existing throughout the Appalachian region and restore them to a more esthetic and productive state.

ACKNOWLEDGEMENT

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The Environmental and Sociological Impact of Recycling of Agricultural Waste by Land Use

by
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INTRODUCTION

New ways of disposing of animal and human effluent are now being demanded in the United States because of the overloading of streams, lakes and rivers, and even our oceans, with pollutants. The nitrogen, phosphorous and organic matter that now pollute our bodies of water are really resources out of place. Green Valley Farms has taken the concept of recycling, refining and utilizing these resources in a beneficial manner to grow crops, instead of allowing these resources to reach either the surface or ground water. If these nutrients are allowed to reach either the surface or ground water, they are then classified as pollutants and are lost to mankind's benefit.

At the Colloquium on Primary Materials Supply and Recycling held at Orleans la Source, France, September 27-29, 1973, part of the general conclusion states, "At one extreme, in the rich countries, solid wastes amount to an average of 20 tons per person each year. This includes about 10 tons of agricultural waste, 8 tons of mineral wastes and more than 2 tons of urban refuse (municipal, commercial, domestic)." Of the waste produced per person in the highly industrialized nations, 50% is agriculturally derived. This factor points out the great need for the recycling of agricultural waste to maintain a clean environment and an adequate and nutritious supply of food for the world population. Green Valley Farms has undertaken a research and development program to recycle cattle wastes back to the land in order to enhance the environment and to help provide a better and more nutritious food supply for our neighbors.

Green Valley Farms is located in New Garden Township, Chester County, Commonwealth of Pennsylvania, United States of America. This is in the metropolitan region of the eastern United States which is commonly termed "megalopolis" and reaches in distance from Boston, Massachusetts, in the north, to Washington, the Capitol of the United States, on the south. The very location within this urban megalopolis area makes the results and acceptance of Green Valley Farms' concept of land use by the community such an exciting prospect for the future.

Short History

Green Valley Farms was established in 1709 and is an original grant from William Penn and has been in continuous operation for 265 years. My grandfather purchased the farm in 1904 and it was operated by him and my father as a dairy farm until 1945 when I continued the operation, wholesaling the milk to the city of Philadelphia.

The location of this farm in New Garden Township, in a rapidly urbanizing area surrounded by a population of 400 people, is a microcosm of almost any metropolitan area in that it has much diversity such as heavy manufacturing and fabricating plants, trucking industry, the world's greatest mushroom growing area, large horticultural greenhouses producing some of the finest roses for the metropolitan markets, canneries, research and development facilities, electronic manufacturing plants, an airport, golf courses, offices and businesses, stores and suburban homes in the $30,000 to $100,000 price range.

During these 70 years, the whole area has been changing rapidly from rural to urban. As this urbanization came upon us, Green Valley Farms made the decision to remain agricultural in an urban area, and I began to develop the concept of land use to utilize the land to its utmost agricultural capacity. Due to the drought in 1955, the first step towards this goal was the development of water resources by irrigation ponds and the first utilization of spray irrigation in maximizing crop production.

In 1960 we decided to process the milk and sell directly to our neighbors from our plant and store which we built on the farm. The slogan on the jug is "From the blade of grass to the glass." About this time I began to take an active interest as a township supervisor in improving and enhancing the environment of the community. When I was elected to the General Assembly in 1964, I continued this concern with my colleagues in Harrisburg.

These incidents all culminated into the idea of recycling cattle waste by establishing waste stabilization ponds and in a beneficial and economical way apply the animal waste to the ground through a spray irrigation system.

Green Valley Farms recycling program renovates the animal waste by filtering the treated effluent through the soil. The plants utilize the pollutants, i.e., nutrients such as phosphorous, nitrogen, ammonia and organic matter, as part of their food supply. When we discussed our ecological blueprint with Dr. Melnick of Baylor College of Medicine, Houston, Texas, he likened our treatment system to a water

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refinery, taking a crude product (the cattle waste), treating it in stabilization ponds as part of the primary and secondary treatment and then finish refining the product by applying the treated effluent to the ground and crops, and thus extracting the final amount of nitrogen compounds, phosphorous and organic matter. In this manner, the plants and soil are the final extraction process, giving us an end product of exceptionally high quality water returned to the acquifer ready to be drawn upon again for mankind's usage.

Green Valley Farms established a research and development program to determine the environmental impact of land treatment on our environment. At the same time, Pennsylvania State University was developing "The Living Filter" concept. In 1967 we met with Dr. Kardos and his group at the Pennsylvania State University and began to develop the Green Valley Farms recycling system together with a water quality monitoring program. With the help of Dr. Kardos, Dr. Parizek and Dr. Sopper and the GEO Technical Services, our design engineer of Harrisburg, the system was developed and built in 1969 and put into full operation in June, 1970.

RECYCLING PROGRAM OF AGRICULTURAL WASTE

The first full application of the recycling concept was the planting of sudan the latter part of June, 1970, which grew four feet in ten days under the spray irrigation treatment. Our basic raw material to be recycled is the manure effluent discharged by two hundred head of milking cows into two stabilization ponds. The effluent is composed of the manure and urine excreted by the animals, the wash water to cleanse the concrete pads, the milkhouse and milking parlor wastes.

This basic influent, as monitored by Dalare Associates, in the first stabilization pond has a total fecal coliform count of between two and four million, which is reduced in the second stabilization pond to a range from 240,000 to 240 fecal coliform, depending upon sunlight and holding time. The effluent in the lagoons has shown no NO_3, but has a range between 85 to 72 parts per million of ammonia in the first and second lagoon. The five day BOD can average as high as 500 to 600 ppm in the first lagoon to approximately 200 ppm in the second lagoon. Dissolved solids in the primary lagoon range from 1100 to 1200 ppm and decrease to 800 in the secondary lagoon. Phosphates range from 100 to 60 ppm in the first and second lagoon.

This biologically treated effluent is applied to the crops and woodlands by a spray irrigation system. The results of our testing show that the growth of the crops and the woodland removes 99.6% of the ammonia in the treated effluent (there is no NO_3 in the stabilization ponds), as well as 99.6% of the phosphates as PO_4, 5 day BOD, total and fecal coliform, leaving a very high quality water for use again.

The system meets the tertiary requirements of the Pennsylvania Department of Environmental Resources, Delaware River Basin Commission and the no discharge goals of the Environmental Protection Agency of the United States. We, at Green Valley Farms, have been exceptionally pleased with the high degree of efficiency of our refinery in the renovation of the treated effluent.

MONITORING PROGRAM

In its research and development, Green Valley Farms established a quality control program for its recycling of agricultural waste which includes an extensive chemical and biological monitoring system from the very beginning of the refining process to the final finished product of high quality ground water returned for man's use. The chemical monitoring program consists of dissolved oxygen, dissolved solids, phosphates as PO_4, nitrates as NO_3, ammonia plus nitrates as N, 5 day BOD, and ammonia as N. A spectrograph analysis is done at periodical intervals. Also included are aerial infrared photographs taken for further analysis of crop growth and management.

One of the first epidemiological programs in the country for a spray irrigation system was developed in 1972 with Dr. Joseph L. Melnick, Chairman of the Department of Epidemiology and Virology, and Professor Craig Wallis, Professor of Epidemiology and Virology, Baylor College of Medicine, Houston, Texas. Both gentlemen had developed various monitoring apparatus capable of detecting one virus particle per 100 gallons of water. With this exceptionally fine capability of monitoring, Dr. Melnick and Professor Wallis were asked to help us with our virus monitoring program to determine if any viruses were present that are pathogenic to mankind. They also monitored the ground water and the streams within our spray irrigation area for any pathogenic viruses. To this date, none have been found.

The stabilization ponds are monitored on a weekly basis by taking samples from all areas of the pond. Also a program to monitor for shigella and salmonella organisms was established, including typhoid. None have been found to date.

Green Valley Farms spent a great deal of time designing a method of catching the treated effluent from the irrigation sprinkler guns. This collected effluent was put through the virus monitor. Again, no viral pathogens, shigella or salmonella organisms were found.

The program put in practice at Green Valley Farms is considered one of the first of its kind in the country, and many regulatory agencies, environmentalists, scientists and other interested people have spent many hours discussing the development of the virus monitoring system for assuring the safety of the spray irrigation procedure.

It is our belief that the program developed for us by the Department of Virology and Epidemiology, Baylor College of Medicine, could be duplicated and used on a worldwide basis to provide environmental health monitoring in the parameters of viruses in land treatment systems.

With proper monitoring, there is no longer any reason for withholding human wastewater, properly treated to inactivate any viral or other pathogens that may be present, from spray irrigation. Key to the success of such a program is (1) the use of proper treatment to inactivate viruses and (2) the regular monitoring to assure the community that the treatment is effective.

ENVIRONMENTAL IMPACT

Recreation

Green Valley Farms is located in a community of approximately 4,000 people which makes it a good test model for the sociological aspects of a community's response to a land treatment system, i.e., recreation, visual esthetics, open space.

The upper fresh water lake has provided a fishing area for local children and, on occasion, their parents. The irrigated woods is a recreational and nature area for the community around it. Many species of birds and wildlife are found in the woodland and area immediately surrounding it. The areas irrigated in the wintertime and the ice patterns that develop from spraying in the freezing weather provide a very pretty panorama of a winter woodland landscape. The spray irrigation of the woodland not only feeds the trees, but by keeping the area natural, provides an excellent growth of berries and seeds and nuts which birds and wildlife feed on. This extra food supply seems to be one of the key factors to attract and keep the wildlife in the woodland and farming area.

In the spring and summer the wildflowers and woodland plants, as well as the lovely woodland foliage, create a beautiful conservation area. The effluent from the spray irrigation is feeding the woodland area and makes a very delightful nature area as well as a summertime playground for the children when they are out of school. In the fall, sportsmen train their dogs in the general area, and when hunting season arrives, pheasant and squirrel are in plentiful supply. We have posted the large pond so that the mallard ducks, canvasback and other species as well as the Canadian geese are protected. Horseback riding through the woods and the surrounding area is a year round activity. This nature center and wooded area is in the center of a very heavily urbanized area and actually pays revenue to the township through a land tax. We have coined a phrase and have used it in many of our talks and seminars—"Taxpaying open space".

With proper planning and proper management, the results we have seen in the last five years at Green Valley Farms indicate very strongly that the enhancement of the environment by recylcing of animal and/or human waste provides tremendous potential for recreational and esthetically pleasing open space for communities and does not place a burden on the taxpayer. Again, we see the theme of nature and man working in harmony with each other to the greatly enhanced benefit of mankind.

The community's response to land treatment has been a very fine one. We feel this can be duplicated in many areas of our country and throughout the world. It is of prime importance that the community be told of the environmental enhancement of a land treatment system which is of proper design and employs good management, — that it can be an asset to a community by improving the enivronment as well as providing revenue for schools and community services.

ENVIRONMENTAL IMPACT

Agriculture

Green Valley Farms has been irrigating cropland with fresh water since 1955, and in the 1960's with the the help of the Pennsylvania State University began to develop a land disposal system incorporating cattle wastes which had been treated in three stabilization ponds to a high degree of treatment and then released into the stream. We felt this was a tremendous waste of vital resources (both organic and chemical nutrients) which could be used on our land. We consulted with Dr. Kardos, Dr. Parizek and Dr. Sopper of the Pennsylvania State University who helped us develop a living filter system and a monitoring program for surface and ground water. This included streams, springs, shallow monitoring wells and deep monitoring wells.

In 1970 Green Valley Farms started an active land treatment program which eventually evolved and developed into "An Ecological Blueprint for Today".* As previously stated, Dr. Melnick and Professor Wallis of Baylor College of Medicine have made possible the most extensive public health monitoring system for any land treatment system in the country. As we developed our land treatment system, working very closely with governmental agencies and the academic community, we found to our surprise that we were enhancing crop production to an extremely great extent. In meeting after meeting, we had been told that land disposal systems are good for just short periods of time. We are happy to report that just the reverse was happening and that our crops were mining the fertilizer, nutrients and organic matter faster than we could apply them. It was at this point of time that we consulted with Dr. Dale E. Baker of the Pennsylvania State University and requested his help in developing a program that would be geared specifically to maximizing food, crop and timber production from a land treatment system.

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* Copyright, 1972
Benjamin J. Reynolds, Avondale, Pennsylvania
A Manual of Waste Treatment Using Spray Irrigation
AN ECOLOGICAL BLUEPRINT FOR TODAY

We at Green Valley Farms had been interested in the use of aerial infrared photography for a number of years which first put us on the trail of the mining effect of our plants. To the environmentalist this is an exceptionally important item of the whole concept in that the plants utilize and renovate the applied effluent before it can reach the ground water.

In 1972 Dr. Baker began to work with us to develop a system of land treatment that would maximize crop production as well as bring about the highest degree of wastewater renovation possible. The research work done by Dr. Baker during 1972 and 1973 proved conclusively that the treated effluent crops were indeed mining the nutrients very rapidly from the soil. With the aid of his staff, Dr. Baker is now in the process of developing a management program which consists of adding nutrients to balance the treated effluent. This correctly balanced effluent results in maximum crop production with the hybrid seeds and trees which are available to us today.

The work accomplished by Green Valley Farms, Dr. Baker and his colleagues indicate a number of significant items which can have a tremendous bearing on the future of mankind and the quality of life that we will be able to enjoy. At this time, I would like to list the very specific developments that occurred at Green Valley Farms during 1973 and their relation to the above comment relative to mankind.

1.) Due to our program, we were able to maximize soybean production to 76.6 bushels per acre. The national average is 28 bushels per acre. This high yield was unexpected. Our check plot yielded 27.7 bushels.

Soybeans are one of the most versatile crops now known to mankind. The production of soybeans holds a key to the protein needs of the world. They can be eaten as is, as a protein food, or used as a supplement to enhance other foods, or they can be fed directly to animals to make meat protein. The greatest threat to the good health and nutrition of the world is the lack of protein for our young people and our older people. We feel strongly that this research which led us to the discovery of an exceptional soybean production must be amplified by many research institutions and agriculturists the world over. When we consider the anticipated increase of three billion people to our world in the next 26 years, time is running out.

2.) The second development verified by extensive research is that the treated effluent sprayed upon the sudan grass at Green Valley Farms significantly raised the digestible protein content by as much as 30%. This, too, bears a direct relationship to protein for mankind because it lessens the need for edible protein for livestock. The sudan plant was able to synthesize the breakdown of the ammonia in the soil from the effluent into a much higher digestible protein content than is normally expected from this type of grass in our region. Again, it appears we are just beginning to scratch the surface in the utilization of pollution in a highly beneficial manner to mankind.

3.) The third major finding entailed the difference between the effluent treated ear corn and the nontreated ear corn. The nontreated corn produced a low of 75 bushels, whereas the effluent treated corn (same variety of seed, same field) produced a high of 152 bushels. Due to a very wet and cold spring, this corn was replanted on June 10, which was approximately 30 days later than usual for planting in southeastern Pennsylvania. Dr. Baker believes there is a potential of obtaining 200 bushels per acre and, in an exceptionally good year, even higher.

All test programs were significant at 95% and 99% levels, per Dr. Baker's report.*

With this documented research, we feel very strongly that if the nations of the world start immediately to look at the use of land treatment where wanted and applicable for maximizing crop production, we can provide a better food supply than is now grimly projected for the future.

Grassland Farming

Results of our research and work show that grassland farming using the application of effluent by land treatment will become one of the most important aspects to be considered by agronomists in the near future for increased food production.

Much of the grasslands in the world are not suitable to be intensively cultivated and plowed year after year because of their topographical features. The soil conservation programs the world over indicate it is best to keep much of the grassland and woodland in its natural state in order to prevent environmental erosion. These grasslands are often of poor agricultural capabilities as compared to class 1 and 2 farmland. The grassland hillsides can make an ideal place for the application of both animal and human treated effluent and sludge. Usually the best method of harvesting the crops from grassland and steep ground is by cattle and sheep. The alternative to raising of animals on much of the grassland area would be to terrace the land which would be prohibitive in both time and energy. The terraced land would prevent soil erosion.

Our research has shown that we can raise the protein content of certain grasses, making it even more appealing to pasture meat and milk animals on this poorer quality ground. Working very closely together with the soil scientists, agronomists and people actively engaged in animal husbandry, we can utilize land treatment on our grassland areas throughout the world, thereby providing mankind with a much greater supply of red meat than heretofore thought possible.

*Baker, Dale E., et al., "Effect of Waste Disposal on Crops, Soils and Water II. A case study of the use of dairy cattle manure effluent for maximizing crop production"

Finally, the work at Green Valley Farms has shown that timber production of both hard and soft woods has vastly been increased by the use of treated effluent. As the world demands more and more of lumber and paper products, much of the marginal ground that has gone out of production can be brought back into full scale environmentally safe production through the raising of trees for timber and paper by the land treatment method.

SOCIOLOGICAL IMPACT

As part of this manuscript, I would like to present an editorial from the Philadelphia Inquirer, August 24, 1974, entitled "Famine is a World Wide Problem" with the subtitle "The Mark of Cain".

Three basic premises were pointed out in this editorial — a climatic shift produced by the cooling of the earth — the huge rise in the world price of petroleum — the geometric expansion of the world's population.

The editorial mentions that the cooling of the earth has caused severe droughts across much of Africa and Asia. The extremely high price of petroleum products has contributed drastically to the rise in price of fertilizer which is so badly needed to provide adequate supplies of nutritionally balanced food. The geometric expansion of the world's population applies the same demand geometrically upon our food supply.

The research and development that has been carried on at Green Valley Farms, we feel, will have a tremendous beneficial social impact upon the world in the years to come. I would like to stress them in the following manner:

1. Pollution abatement — removing the pollutants from the animal wastes, thus providing a better and cleaner environment.
2. Removal of the nutrients and organic matter from the animal wastes, thus providing an exceptionally high quality of renovated water to be utilized by mankind for his many needs and uses.
3. The increased crop production resulting from items 1 and 2, (the recycling of agricultural wastes at Green Valley Farms) showed very specifically our ability to double corn production and triple soybean production and vastly increase both the tonnage and protein content of grasses.

The net effect of the ability to enhance crop production by recylcing of agricultural wastes would be to provide a diet substantially increased in both energy and protein. Our civilization is very close to a diet so low in energy and protein content that it can cause tremendous physical and mental damage to many of our peoples throughout the world. This not only can happen to underdeveloped countries but, with the changing climatic and economic factors in the world today, can happen also to our developed countries. We feel very strongly that our concept of recycling animal waste can be applied as well to recycling of human wastes with the same results and can be one of the major factors in meeting the world food crisis that appears to be bearing down upon us. Not only a very beneficial environmental impact, but a beneficial sociological impact to our world's people would seem to be the net result of our research and development program.

Experience with Land Application of Wastewater and State Regulations
The Pennypack Watershed

by
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INTRODUCTION

Engineering environmental consultants have long been concerned primarily with their own specialized field, either storm water runoff and associated flooding or water supply and its source from either surface or groundwater or wastewater collection, treatment and discharge. The fact that all of these activities are directly or indirectly interconnected has been ignored by most consultants in the past; however, the effects of each of these activities on the others is significant. All of these activities are related to each other in that they are important elements of the water balance for a basin or a region. Disruption or displacement of water in this balance can have significant beneficial or adverse effects. An evaluation of a water balance requires an analysis of the sources of water, losses of water and the impact or impacts of this net change.

WATER BALANCE

The major sources of water are rainfall and imported water (Figure 1). The imported water may be in the form of potable water for public water supply, or wastewater for disposal. The major loss of water from an area is by evaporation and transpiration. In addition, runoff and exportation of water in the form of potable water or sewage can represent major losses. Once the net gain or loss has been calculated, the impacts can be itemized. Unfortunately today in urban watersheds, we find that the principal impacts are adverse in that they represent water loss. This commonly causes the creation of dry streams with associated loss of stream amenities, both aesthetic and physical. In addition, we find that the loss of water due to water exportation results in a loss of surface and subsurface water supplies.

The Pennypack Watershed is a classic example of the need to understand the water balance so that future development is planned to have a minimal adverse effect upon this water balance (Figure 2). The Pennypack Watershed encompasses 56 square miles with partially undeveloped land in the center of the basin. The major source of water is precipitation. In addition, water is imported from an adjoining basin to support the demands for a potable public supply. The major water loss from the basin is in the form of evapotranspiration. Other water losses are surface water runoff, and sewage that is exported to two adjoining basins one of which presently has a water deficit.

Precipitation + Importation = Evaporation + Transpiration + Runoff + Exportation

FIGURE 1. NORMAL WATER BALANCE

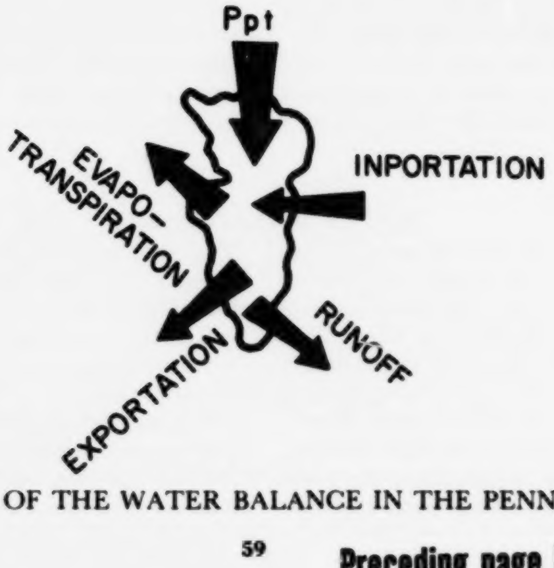

FIGURE 2. ELEMENTS OF THE WATER BALANCE IN THE PENNYPACK WATERSHED

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THE PENNYPACK WATERSHED

Let us look at the amounts of water that constitute the water balance in the Pennypack Watershed (Figure 3). Annual precipitation is 44 inches or 43 billion gallons of water per year on the 56 square miles of the watershed. Water imported into the basin for public water supply represents an estimated 2 billion gallons per year. The losses of water from the basin are evapotranspiration - 28 billion gallons per year, wastewater - 9 billion per year and a *minimum* of 4 to 6 billion gallons per year of base flow in the Pennypack Creek. The system today is precariously balanced. Heavy rainfall in the developed areas of the watershed produce rapid runoff which results in flash flooding along several of the tributaries and the main stem of the Pennypack. Periods of below normal rainfall have just the opposite effect with stream flow dropping dramatically. In the upper reaches of the basin which are already intensely developed and sewered, the main stem of the Creek drys up completely. During drought periods the central part of the basin has had stream flows of only 3 or 4 c.f.s.

SOURCES				**LOSSES**				
Ppt		**Imported**		**E−T**		**Runoff**		**Exported**
43	**+**	**2**	**=**	**28**	**+**	**4−6**	**+**	**9**

FIGURE 3. VOLUMES OF WATER IN THE PENNYPACK WATERSHED EXPRESSED IN BILLIONS OF GALLONS PER YEAR

EFFECTS OF DEVELOPMENT

The water balance today in the Pennypack Basin is precarious due to man's previous activities in the basin that have upset the water balance. We are faced with a time of decision. Shall this basin become another urban watershed with a paved, dry, stream bed, except in periods of storm when we have flash flooding? Unrestricted land development in the basin will have a negative impact on the water balance (Figure 4). With development comes increases in impervious surfaces and storm sewers. This produces rapid collection and runoff of storm water, prohibiting its natural recharge into the groundwater. With development also comes a greater demand for water supply. Available water supply in the basin is decreased due to a lack of recharge of the local groundwater and a lessening of the base flow in the stream due to the lowering of the water table.

One method to re-establish the water balance could be the importation of water from a neighboring watershed, but this merely shifts the adverse effects from one locale to another and the domino theory comes in to play. As one watershed becomes deficient in water, it imports water from an adjoining watershed. This one then becomes deficient in water and imports from the next watershed, and so on and so on. With the energy crisis this country faces for the next decade, we must also evaluate the energy requirements of inter-basin transfer of water. Added to this is the capital expenditure for water transportation facilities. With the condition of the money market today and in the forseeable future, inter-basin transport of water becomes highly questionable. A second method that is widely recommended is the use of storm water for groundwater recharge. This requires the retention of the storm water, its treatment, and recharge to the groundwater, either by spray irrigation or by seepage beds. However, in most of our urban watersheds today, undeveloped, properly located and suitable land is nonexistent and treatment facilities for such a system are prohibitively costly.

WATER MANAGEMENT

There are two other alternatives that may be considered. One is zero development, which is unrealistic in urban watersheds. The second is restricted development with concurrent land disposal of treated wastewater (Figure 5). With restricted development there will be fewer paved areas and a corresponding decrease in surface water runoff and increased natural recharge as compared to unrestricted development. Also because of the controlled development there will be a lessening of the demand for public water supplies. The retention of open space will permit larger amounts of water to infiltrate into the groundwater than with dense land development. In addition, there will be the beneficial effect of the spray irrigated water which will supplement natural groundwater recharge. Comparison of unrestricted development and restricted development with spray irrigation will lessen water demand, increase natural recharge and is a most effective method for maintaining the water balance in a basin (Figure 6).

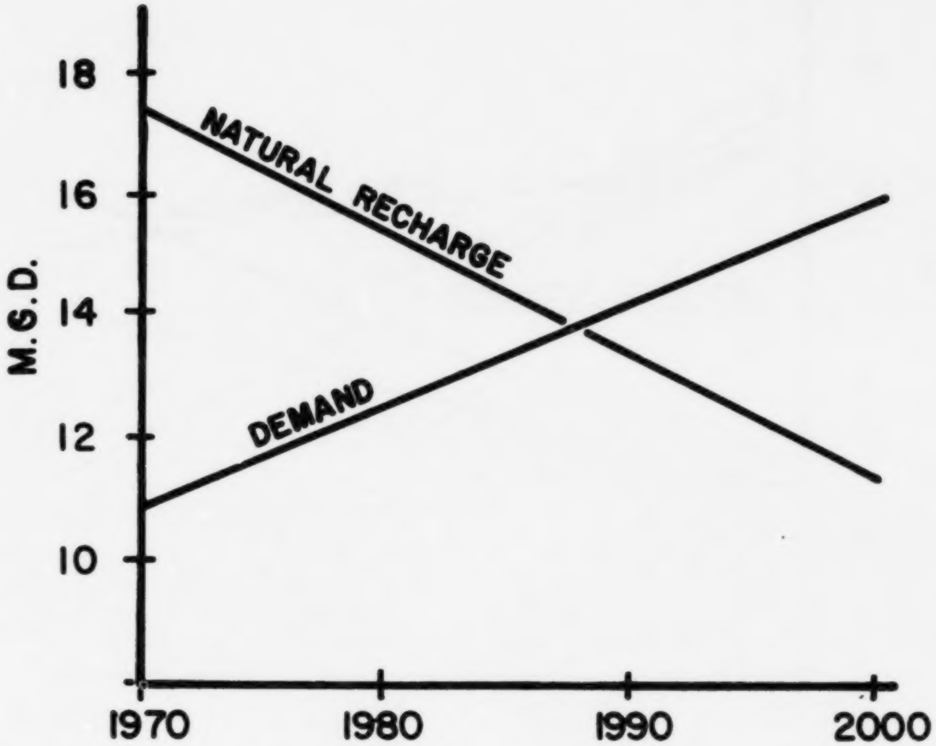

FIGURE 4. THE EFFECTS OF UNRESTRICTED LAND DEVELOPMENT ON THE WATER BALANCE IN THE PENNYPACK WATERSHED

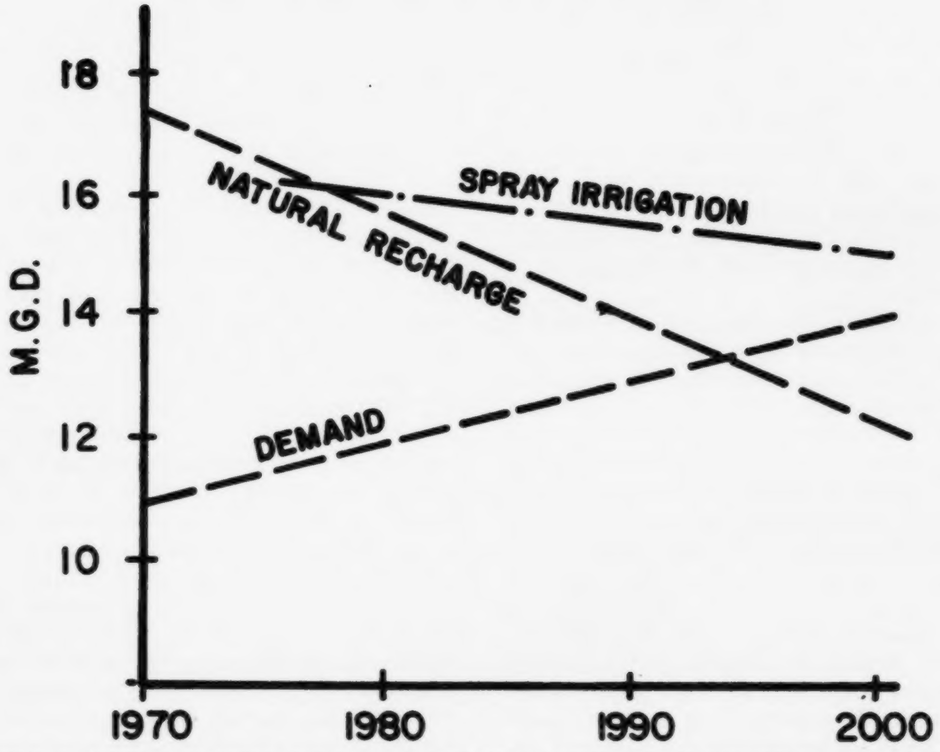

FIGURE 5. THE EFFECTS OF RESTRICTED LAND DEVELOPMENT ON THE WATER BALANCE IN THE PENNYPACK WATERSHED

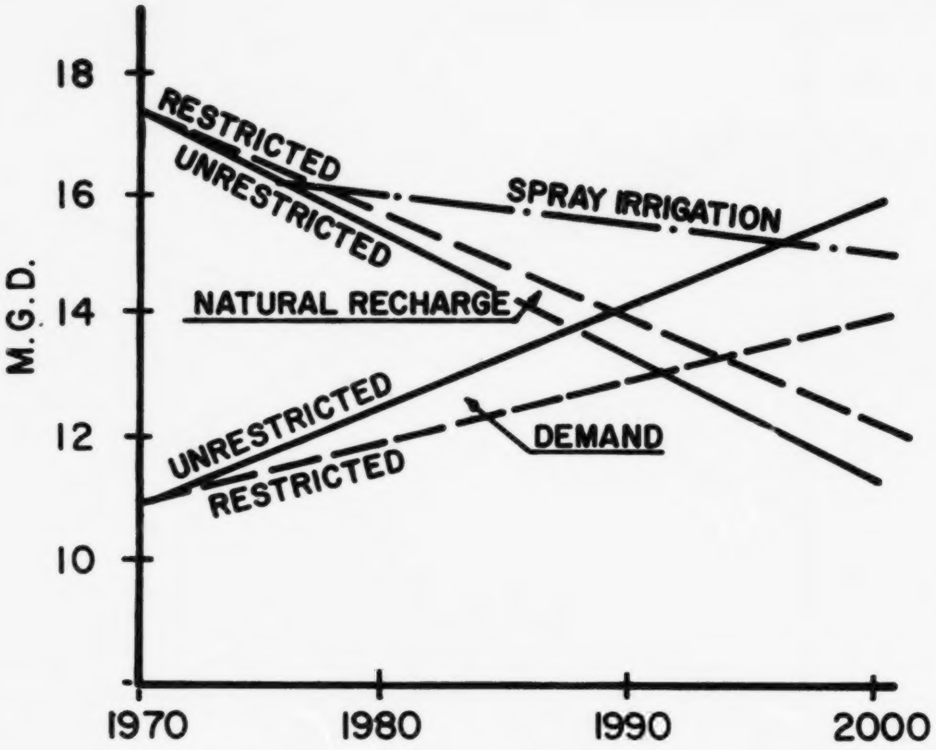

FIGURE 6. COMPARISON OF RESTRICTED AND UNRESTRICTED LAND DEVELOPMENT ON THE WATER BALANCE IN THE PENNYPACK WATERSHED

SPRAY IRRIGATION BENEFITS

Evaluation of the soils, geology, and hydrology of the Pennypack Watershed indicate that it is capable of accepting up to 4-1/2 million gallons per day or 1.5 billion gallons per year of treated wastewater. This could create a significantly desirable effect on the base flow in the stream and especially the tributaries near the spray areas or could be developed as a groundwater supply.

The average rainfall in the Pennpack Watershed is approximately 44 inches per year. Of this amount, approximately 29 inches is evapotranspired back to the atmosphere. The remaining 15 inches infiltrates into the ground and eventually discharges into the stream as base flow or else represents immediate storm runoff. Let us assume 2 inches per week of treated wastewater is spray irrigated onto a site. This is the maximum permitted by Pennsylvania State Regulations today. The 2 inches per week would represent 104 inches per year minus evapotranspiration losses. Studies at Penn State indicate that even during severe drought conditions in 1964, almost 80 percent of the applied treated wastewater infiltrated into the groundwater reservoir. Assuming 80 percent of the spray irrigated water does infiltrate, this will add 83 inches of additional water to the groundwater reservoir every year. This represents 2-1/4 million gallons additional recharge per acre, per year. The Pennypack Watershed has land available that is capable of accepting up to 4-1/2 gallons per day or 1-1/2 billion gallons per year of treated wastewater through spray irrigation. This additional water would have a significant effect in supporting base flow of the tributaries and the main stem of the Pennypack in the middle and lower thirds of the basin, especially during low flow periods. It also would be possible to selectively develop water well fields, contiguous with the spray irrigation fields. It is estimated that 50 percent of the spray irrigated water could be recaptured in these wells and utilized for public water supply. The remaining 50 percent would then supplement the base flow in nearby streams. The physical dependency of spray irrigation systems on open lands would thus control development within the basin. This would result in limited water demand and maintain multi-purpose open spaces. The spray irrigated open spaces could be used for crop production, wild-life sanctuaries, or recreation areas. State regulations in Pennsylvania now encourage spray irrigation once a week. This retention of the open space will also permit natural infiltration of rainfall and the recharge to the groundwater instead of maximizing runoff and flooding from densely developed, paved areas.

REGULATIONS

Regulations of the Pennsylvania Department of Environmental Resources has failed to address total water management and the water balance. Their concern has been only with water quality. This has lead in the recent past to the development of massive regional sewage treatment plants which have extensive collection systems. Justification for this has been that it is most cost effective. Exportation of the water through the regional collection system has resulted in numerous dry streams. Any improvement in quality has been offset by significant decreases in quantity in urban areas. In this cost effective analysis they have ignored the consideration of water quantity. The fact that regional wastewater systems export water from a basin with a resulting negative impact on the water balance has been ignored. This is a very vital factor. Any cost effective analysis must include the negative effects of water exportation. The 1972 amendments to the Federal Water Quality Act clearly requires consideration of alternative methods and mandates a comprehensive cost benefit analysis. Proper analysis of the cost benefits should include the cost of replacing water exported from a basin by a regional wastewater collection system. It should also include as a benefit, the retention of water in a basin for re-use through recycling of the wastewater in a spray irrigation system. Proper analysis of cost and benefits must include the complete cycle of water from use, treatment, discharge and return to the user in a potable form, or the replacement costs if it is exported. With this approach for considering the water balance in a basin, it will readily be seen that spray irrigation is the most cost effective method for wastewater treatment in the Pennypack Watershed.

Experience with Land Application of Wastewater and State Regulations Pennypack Watershed-Pennsylvania

by
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Senator Henry Jackson observed recently that "all environmental problems are outgrowths of land use patterns."[1] He might well have added that land use patterns are substantially influenced by sewage facilities. In all too many cases, this vital relationship between sewage facilities and future land use patterns has not been adequately studied or understood. A better framework for sewer planning is urgently needed if we are going to restore sanity in the future development of the heavily populated Eastern seaboard.

The Pennypack Watershed Association was formed in 1970, for the purpose of providing citizens and governments within the watershed with the means to plan, develop, and implement a suitable program of watershed management. Paramount in its responsibilities is to insure a quality environment. This includes adequate supplies of clean water, open space for conservation and recreation, protection of flood plains, reduction of soil erosion, maintenance of natural habitats, and land use planning in harmony with natural resources.

The Pennypack Watershed encompasses a 56 square mile area, including parts of Montgomery, Bucks, and Philadelphia Counties and eleven municipalities. The lower 1/3 of the watershed is within the City of Philadelphia, and is highly urbanized. The upper 2/3 of the watershed lies within suburban Bucks and Montgomery counties. The uppermost section of the watershed is undergoing rapid urbanization, while the central portion, contrary to typical watershed patterns, has so far remained a unique "island of green living space."

The watershed population in just the past four years has risen from 243,000 to 270,000 residents, an 11% increase, which already exceeds the 1980 forecast. Unless innovative forward looking plans are implemented in the near future, the amenities and resources of the Pennypack Watershed will be lost forever.

The Pennypack Creek has historically been utilized for water supply and water-based recreation. Development pressures in combination with conventional and outdated sanitary engineering approaches have created severe water quantity and quality problems, particularly during the past decade. The Pennsylvania Fish Commission ceased its fish stocking program in the Pennypack Creek in 1969, for "aesthetic reasons."

The Montgomery County and Philadelphia park systems along the creek have erected health hazard warnings to alert the public, and a major local water company stopped taking its supply from the Pennypack because of water quality problems. A large sanitary waste treatment plant (6.6 MGD) in the upper portion of the watershed, which is presently operating under a ban on additional connections, has constituted a significant part of the pollution problem.

A most ominous long-range threat to the watershed's future is posed by a proposed interceptor pipe (4.45 MGD by 1995), designed to service two major central watershed communities, utilizing outdated plans which are essentially fifteen years old. The proposed interceptor would export wastes to a major regional treatment plant in Northeast Philadelphia on the Delaware River, below the mouth of the Pennypack.

The interceptor would exert a negative influence on the watershed in a number of significant ways.

First, the interceptor would export a large quantity of water from the central watershed. This water is essential in order to preserve the proper water balance of both the tributaries and the Pennypack Creek, especially during low-flow periods. The exportation scheme would rob the region of a valuable future source of local water supply. It would substantially downgrade the recreational values of the park systems along the Pennypack and frustrate attempts to restore stream habitats.

An equally alarming aspect of the proposed interceptor is the predictable effect that it would have in generating more unplanned growth. It is an irony, for example, that part of the design capacity for the proposed interceptor assumes that a local golf course will be developed into a residential tract, and that additional land lying within a flood plain will be developed for commercial purposes. The very same pipe that is exporting the water supply, will generate new demands for water. Thus, the future scenario becomes clear. Remaining open space will be threatened, existing flooding hazards will be aggravated due to increased urbanization, ground water re-charge will be further reduced by the addition of impervious surfaces, and thus, generally compound the adverse influences that already are set in motion

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[1] *Natural History* — page 76 — "The Use of Land" — April 1974

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against a quality environment for the citizens of the Pennypack Watershed.

Turning our attention now to the upper watershed, we see another problem emerging. The upstream treatment plant, which has for years constituted a major source of pollution, is now being planned to undergo substantial enlargement. While this plant would not present the water exportation problems of the central watershed interceptor, it would in view of its very size (12.0 MGD) severely stress the assimilative capacity of the Creek at the single point of discharge—even if very high levels of treatment are obtained, which remains suspect in the light of past experience. In addition, the enlarged plant would generate additional development pressures and the related problems cited above. Since the upper portion of the watershed is heavily dependent upon wells for its source of water supply, the consequence of future development preventing ground water re-charge becomes even more apparent.

Meanwhile, a central watershed municipality, in cooperation with the Pennypack Watershed Association, has applied to the Pennsylvania Department of Environmental Resources for a regional spray irrigation system, which is in conflict with the two other proposals cited above. I will touch on this proposal in more detail later.

It might be useful to note at this point that all of the problems that I have discussed here stem from one glaring failure in the planning process. This may be summarized as a failure to understand the principle that all sound planning *must* have as its foundation a soundly conceived program of resource management on a regional watershed basis.

We must put an end to the chaotic conflicts which have been engendered by a failure to see the relationship between land use patterns, sewer planning, and resource protection. Sewer planning must no longer remain solely in the domain of the sanitary engineering profession. We can no longer afford the mounting social costs that result from this kind of tunnel vision, all too often under the guise of economic necessity and the exercise of local rights. Are we so blind that we can't see the need for a sounder framework for our decisions?

While the trend during the past decade to larger treatment plants has been described as "regional planning" such a program can hardly be described as resource protection, when the aftermath results in dry stream beds, unplanned development, and costly systems, which on the one hand export waste-water and on the other hand re-import water through inter-basin transfers from other regions.

The only water plans now in existence for the watershed are the sewage facility plans for Bucks, Montgomery, and Philadelphia Counties, prepared as official ten-year plans for sewage facilities in accord with the provisions of the Pennsylvania Sewage Facilities Act (Act 537 of 1966).

These plans were all incorporated into the Delaware Valley Regional Planning Commission's "Regional Water Pollution Control Plan." The lofty title disguises the reality that the plans are essentially piecemeal, fragmented attempts to solve short-term problems, with little attention devoted to real water resource management issues or long-term effects.

It is interesting to note, for example, that considerations for watershed-wide planning are advanced in the recommendations of the Montgomery County Sewage Facilities Plans . . . "that the environmental impact of new sewage facilities be carefully reviewed . . . that maximum benefits can best be attained by implementing the principles of watershed-wide planning."[2] And yet the adopted plans almost totally ignore these recommendations. This is not really surprising, since the county's consultants were limited to a $100,000 budget, an amount less than 1/10 of the 1% of the estimated cost for implementation of the sewage facilities, which was estimated to be $66 million.

Until very recently, the full responsibility for sewer planning has rested with the local municipalities, and authorities. The past bears testimony to the fact that this fragmented system of responsibility and financing, which is user oriented, will never achieve meaningful watershed-wide objectives. The local municipal authority quite naturally perceives its role as one of getting the water wastes out of the community at the lowest possible cost. Although vested with the major responsibility for sewer planning, the local authority has no real responsibility or legitimate concern for "the bigger picture" which includes water resource management, land use, and watershed concerns. This is an approach which has to be described as "penny-wise and dollar foolish."

It should be acknowledged that the Pennsylvania Department of Environmental Resources is slowly beginning to recognize some of these problems, but even in its new state wide, watershed-oriented sewer studies, known as COWAMP, the major emphasis still appears to be on water quality, with little real focus on water quantity and resource issues.

While Public Law 92-500 represents progress, by broadening its concern with land use and environmental issues, it, too, appears to have the defect of being "point source" oriented, and does not adequately address itself to water quantity and watershed management. I am very encouraged, however, by the fact that the EPA now requires that any application for a construction grant must contain adequate data and analysis to demonstrate that the proposed facility reflects the most cost effective alternative over the life of the facility. I also derive encouragement from former Governor Peterson's recent public statements that link new sewer capacity to its effect on development. To quote Mr. Peterson: "These land use and energy impacts are not being identified and evaluated as part of the grant award process."[3]

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[2] *Montgomery County Sewage Facilities Plan* — page X-12

Now let me return to the Pennypack and describe what the Pennypack Watershed Association is doing about these problems. The Association from its inception, has recognized the need to develop a water resource management program for the watershed. It received approval from the EPA in 1972 for a research grant application entitled "Environmental Restoration Using Local Watershed Planning." Unfortunately, this was never funded. Recognizing the urgency to develop sound alternatives to the existing fragmented sewage plans, the Pennypack Watershed Association, with the cooperation of a central watershed municipality, proceeded on its own.

Working with a team of consulting engineers, hydrologists, and other specialists, the Association had identified, in the central watershed, more than 600 acres of land eminently suited for employing spray irrigation systems, which could handle up to 4 million gallons per day of secondarily treated sewage. Extensive discussions have been held with property owners to obtain their participation and acceptance of the proposal. In addition, the Pennypack Watershed Association has identified a significant amount of additional land, both upstream and downstream, which would be suitable, including golf courses, and vacant lands, which might otherwise be lost through development. The system contemplates pretreatment by the use of secondary treatment or aerated lagoons.

Many of the future spray irrigated sites surround a proposed 700-acre Wilderness Corridor, of unique value, which will be owned and operated by the Association for educational and passive recreational purposes. It is contemplated that the property owners of spray sites will enter into a long-term lease with the sewer authority, with the Pennypack Watershed Association exercising part of the monitoring responsibility.

The spray sites will serve to preserve open spaces on a long-term basis, and will protect and enhance the environment of the region. Conversely, if the conflicting interceptor proposal is approved, these open spray sites would likely be lost to development and, thereby, stimulate the need for additional interceptor capacity.

Besides re-cycling needed waters and nutrients, the spray sites will be available for multiple uses, such as wildlife habitats, agriculture, and recreation, and will also provide a useful buffer to the central creek-based Wilderness Corridor.

The benefits of the proposed spray irrigation system, conceived on a watershed-wide basis, may be summarized as follows:

1) Water resources will be re-cycled to re-charge ground water, maintain water balance, and augment stream flows.

2) Future water costs can be held down by obviating the necessity for tertiary treatment and for additional water importation schemes.

3) The Living Filter techniques will improve water quality, and quantity, and avoid heavy point source loads.

4) Integrity of local planning will be preserved through preservation of open space for multiple uses, which in the alternative would stimulate new development and create additional demands for sewer capacity.

5) There will be substantial energy savings by using natural systems versus conventional treatment methods, and by reducing the need for chemical fertilizers, and treatment chemicals.

6) The preservation of open space will minimize flood hazards, surface run-off, pollution and siltation.

Local tax bases will not be adversely affected, since the region's land values will be enhanced and demand for costly additional community services minimized.

7) Environmental damage due to construction of interceptor pipe will be eliminated.

8) Stream biota and wildlife habitats will be enhanced, air quality improved, and the recreational and aesthetic enjoyment of the area restored.

Now let me briefly summarize where this effort stands today. Following more than a year of constant prodding by the Pennypack Watershed Association, the Pennsylvania Department of Environmental Resources has now hired a consultant to more fully evaluate this alternative proposal, and is prepared to go back to step one in the planning process. Meanwhile, the EPA has set aside the conflicting applications in the Pennypack Watershed, until a complete evaluation is made.

We sincerely hope that the state will make a serious effort to make a comprehensive evaluation of all the relevant issues. The Pennypack Watershed Association, for its part, would far prefer state and federal cooperation in this matter, in lieu of costly and time consuming litigation.

Let me close by acknowledging that we recognize that spray irrigation is not a panacea for all problems, but we also ask the sanitary engineers to acknowledge that their plumbing solutions have rarely addressed themselves to fundamental resource questions. Scarcely a treatment plant in the country consistently removes the high fractions of BOD solids and pathogens, which its design consultants promised it would, and as a consequence, we have seen our legacy of once sparkling streams reduced to the functional status of open sewers. I would, therefore, ask this esteemed profession to look at the problems inherent within their conventional systems, with the same diligence that they question problem aspects of spray irrigation. And finally, let us be honest in the discussion of alternative costs to include *all the costs*, both tangible and intangible, or otherwise we will continue to perpetuate the sins of the past.

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[3] *New York Times* — page 16 — "E.P.A. Is Curbing Sewer Main Subsidies" — October 15, 1974

Land Disposal of Wastewater in the Commonwealth of Pennsylvania

A Regulatory View

by
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The land disposal of wastewater is a concept which has developed due to increasingly stringent water quality requirements for the discharge of wastewater to streams and the need for adequate wastewater treatment and disposal in areas where streams are not readily accessible. Spray irrigation in Pennsylvania appears to be the most popular and successful of the various methods of land disposal; which includes spreading by tank truck on the land, ridge and furrow irrigation, overland flow, infiltration ponds or trenches, and surface flooding.

Spray irrigation is the application of liquid wastes evenly on the land surface by aerial dispersion for treatment and or ultimate disposal It is normally the final stage of a wastewater treatment system, since additional treatment is obtained through soil renovation when the wastewater is sprayed onto the land. The ground-water quality or quantity may in some cases be altered but pollution of ground water or surface water will not be permitted as a result of spray irrigation. In Pennsylvania the quality of all waters, regardless of their physical location, are subject to regulation under the State's water pollution control legislation.

The Clean Streams Law of Pennsylvania, as amended by legislative sessions in 1970, is the basis for rules and regulations to protect surface water and ground water.

"Waters of the Commonwealth shall be construed to include any and all rivers, streams, creeks, rivulets, impoundments, ditches, water courses, storm sewers, lakes, dammed waters, ponds, springs, and all other bodies or channels of conveyence of surface and underground water or parts thereof, whether natural or artificial, within or on the boundaries of this Commonwealth".

The law stipulates that discharges of sewage, industrial wastes, or any substance to the waters of the Commonwealth which causes or contributes to pollution or creates a danger of pollution is declared not to be a reasonable or natural use of such waters. No person or municipality shall discharge or permit the discharge of industrial waste or sewage in any manner directly or indirectly into the waters of the Commonwealth without a permit, unless such a discharge is authorized by the rules and regulations.

Since a large amount of wastewater discharged to the land surface will infiltrate and recharge ground water, all spray irrigation installations are considered discharges to the waters of the Commonwealth. The department of Environmental Resources, under the Clean Streams Law, uses a permit system to regulate: the location and installation of facilities, conduct of operations, protection safeguards, and monitoring activities for the facility . . . The Bureau of Water Quality Management of the Pennsylvania Department of Environmental Resources is the regulatory agency concerned with the protection of the waters of the Commonwealth. As such, it has been involved in the development of spray irrigation as a satisfactory renovative tool for quite some time. We feel the point has been reached where spray irrigation is considered a viable alternative in the treatment and ultimate disposal of wastewater. A regulatory agency has an obligation to consider all techniques of wastewater disposal and to assess their applicability to various wastes, as well as their impact on the environment. Problems which were recognized from the earliest days of our experience with operating spray irrigation systems indicated that regulation is needed. The imposition of regulation, however; carries with it a responsibility to provide guidance in the construction and location of such facilities so that the potential user can develop a plan satisfactory to the regulatory agency.

Spray irrigation has been going on in Pennsylvania at least since the late 40's. The main users, here-tofore, have been agribusinesses, who have used spray irrigation to dispose of their excess process water at various locations. Spray irrigation has been used outside the Commonwealth for a much longer period of time. Interest has continued to grow in the use of spray irrigation due to its many benefits. Approximately five years ago, The Department determined that interest in the technique was so strong that a manual was needed to guide consulting engineers and concerned persons desiring to use spray irrigation to meet their needs. It should be pointed out, that, while this interest was developing, the Department was becoming increasingly aware of the need to protect the quality of ground water. Severe ground-water pollution was observed from various solid and liquid waste disposal facilities, and some facilities that were not causing problems posed a tremendous pollution potential.

Historically, the emphasis has been to protect sur-

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face water with little or no thought given to ground water. Ground water is not visible and as a result, is generally overlooked (out of sight; out of mind). Discharges to ground water and land disposal of waste and wastewater have been considered by some to be the ideal treatment technique because they are not direct discharges to surface waters and, therefore; thought not to affect surface water quality. Effective water quality management programs cannot deal with the surface water alone. Non-point sources of all water in surface streams originate from either direct runoff or ground-water discharge. During the dry times of the year, from August to October, the stream flow may be as much as 100% ground-water discharge. It is obvious that the quality of surface water can only be as good as the quality of ground water. The protection of ground water is considerably more complicated than that of surface waters. A direct discharge of a polluting substance to surface water needs only be stopped and in the matter of days or possibly months, the stream will usually revert to its original quality. On the other hand, water within the ground moves painfully slow and the flow may be measured in feet per day to feet per year. Thus, once ground water is polluted, it may take tens of hundreds of years to restore it to its original quality.

The Department of Environmental Resources published its spray irrigation manual in 1972. This manual is written for a wide audience including the professional design engineer, earth scientists as well as others who need to be aware of the techniques and technology of spray irrigation. It sets forth certain criteria primarily as guidelines, based upon the spray irrigation of treated sewage effluent. Throughout the manual there are numerous statements which demonstrate the Department's intention to be flexible and willing to consider special applications and designs.

Spray irrigation should only be used in situations where the wastewater contains materials of such type and concentrations that they can be renovated in the soil mantle and do not pollute ground water. Generally, the equivalent of secondary treatment must precede the irrigation. Allowance for variability of earth materials, spray field use, and effluent constituents is considered in reviewing proposals on a site by site basis. The prime consideration for site selection is the ability of the organic and earth materials to properly treat the wastewater.

Like all rapidly developing technologies, waste treatment and disposal by spray irrigation has suffered from some misunderstanding, inadequate design, mismanagement, and misapplication. conversely, it shows great promise as a valuable alternative technique for wastewater management. A new attitude of environmental understanding is necessary by all potential users of spray irrigation. The key to this understanding is the acceptance of the basic tenet that spray irrigation must be integrated into the environment rather than imposed upon it.

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Overland Flow Treatment of Wastewater – A Feasible Approach

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INTRODUCTION

We have discussed in previous chapters how wastewater is renovated as it moves through the soil profile at either slow or rapid rates. Numerous systems that have been operated successfully for many years can be cited for slow infiltration or crop irrigation and rapid infiltration treatment methods.[10,11,12,13,14] Through years of experimentation and study, a good understanding of the mechanisms involved in these treatments has developed. At the risk of alienating readers who have a different view, we would state that no other method of advanced treatment of wastewater has such a profound background of performance and mechanistic theory as crop irrigation or rapid infiltration. There is no justifiable reason for these methods to be ignored by administrators, engineers, or scientists as alternatives for wastewater treatment.

Since the slow and rapid infiltration systems are reliable and well understood, it might be questioned as to why overland flow is needed. the rather obvious answer is that on many soils of low permeability, wastewater can neither penetrate nor move through the soil profile; therefore, treatment by interaction with the soil mantle is not possible. This lack of penetration and movement can result from a number of conditions, but the most common are low hydraulic conductivity in heavy textured soils and barriers of various types within the upper 3 ft of soil profiles. Slow and rapid infiltration systems will not function well in these situations. However, these are the soil conditions that are required for overland flow treatment.

In contrast to slow and rapid infiltration, the treatment of wastewater on soils of low permeability by overland flow has not been well understood in the past. However, in recent years we have begun to understand to a much greater extent how overland flow systems function. We can see an analogy to the development of rapid infiltration. While these are similarities between slow infiltration and rapid infiltration, rapid infiltration systems will only function if the soil profile is oscillated between significant periods of aerobic and anaerobic conditions.[1] This is a condition not obtained in classical slow infiltration or crop irrigation systems where prolonged anaerobic periods would cause soil clogging and crop damage.[8,16,17] The potential of rapid infiltration systems became evident only after it was recognized that these systems functioned differently than crop irrigation systems but on very understandable and manageable principles. Similarly, overland flow systems must be constructed and operated differently from either slow or rapid infiltration systems in order to realize the potential for treating wastewater on soils of low permeability.

The successes of a limited number of overland flow systems and the research models that respond as predicted by theory lead us to the conclusion that overland flow is a feasible approach to the advanced treatment of wastewater in many areas. The following sections present an overview of system operation and theory for overland flow treatement of wastewater.

WHAT IS OVERLAND FLOW TREATMENT?

A schematic representation of an overland flow system is depicted in Figure 1. In an overland flow system, the wastewater is applied at the top of gentle sloping hills and is allowed to flow over the soil surface down to the collection channels. Note that treatment is represented as an intimate interaction among the soil surface layer, surface organic mat, plants, and microorganisms. The common length of slope is 100 to 300 ft, and normally the system is employed on slopes ranging from 2 to 8 percent.[3] Application rates are low, generally less than 0.5 acre-in. per day, but wastewater is applied for five days per week. Thus weekly application rates are approximately 2.5 acre-in. These rates are comparable to those used on slow infiltration-crop irrigation systems. The ability to monitor wastewater as it leaves the treatment site is an especially valuable characteristic of overland flow systems. Most of the treated wastewater is availalbe at central collection channels for quality determinations and for discharge or other desired uses.

A good example of an overland flow system is the Campbell Soup Company's plant at Paris, Texas (Figures 2,3, and 4). The lush grass growth and sloped surface are shown in Figure 2. During wastewater applications, a film of water moves across the soil surface as shown in Figure 3. It should be noted that this film of water moves over the soil surface and through an organic mat that is predominantly composed of plant residue and grass roots that grow on or near the soil surface. This organic mat is believed to be very important to both the biological and chemical functioning of the system. The point discharge of treated

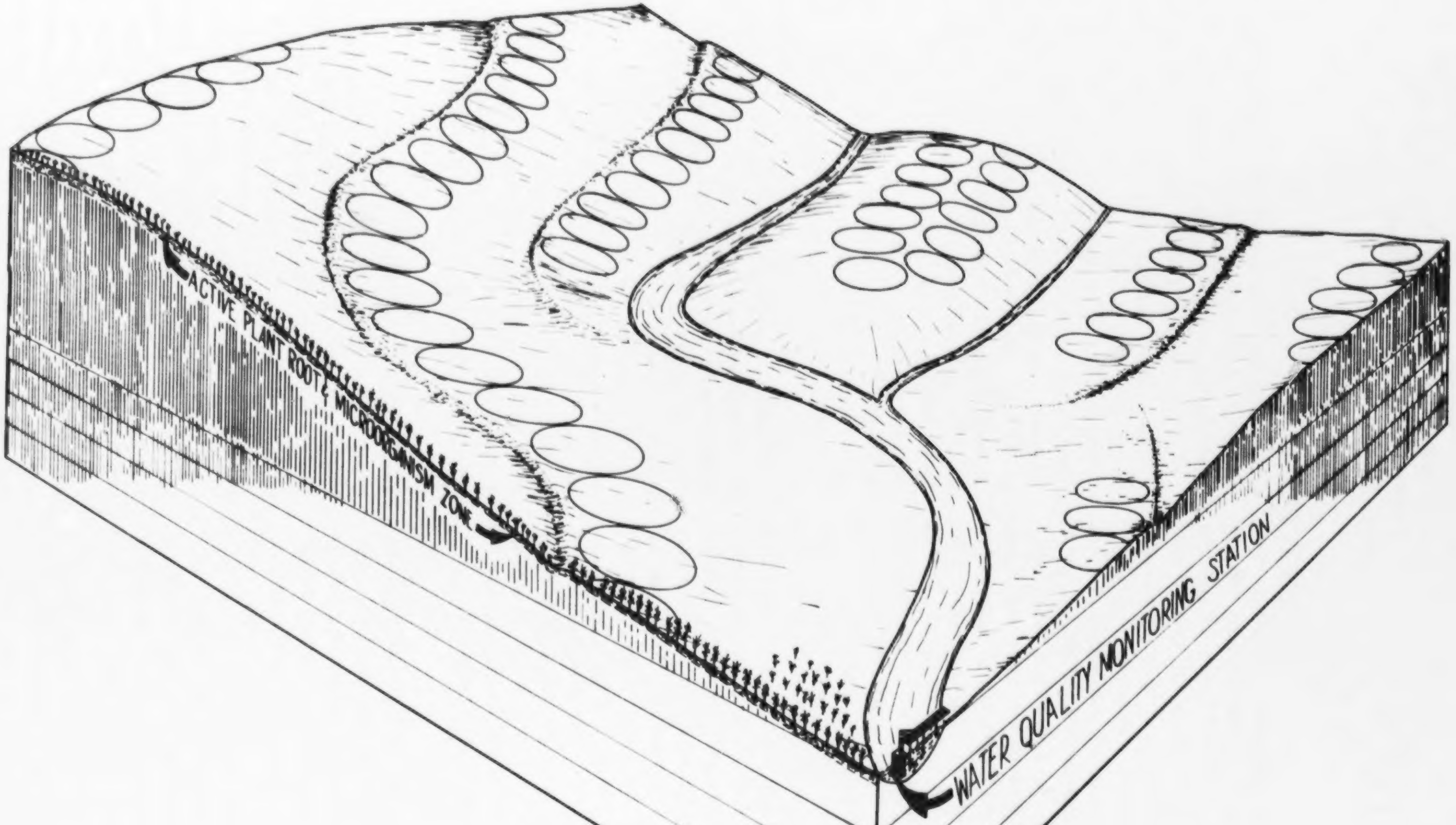
ACTIVE PLANT ROOT & MICROORGANISM ZONE
WATER QUALITY MONITORING STATION

FIGURE 1. SCHEMATIC DIAGRAM OF AN OVERLAND FLOW SYSTEM.

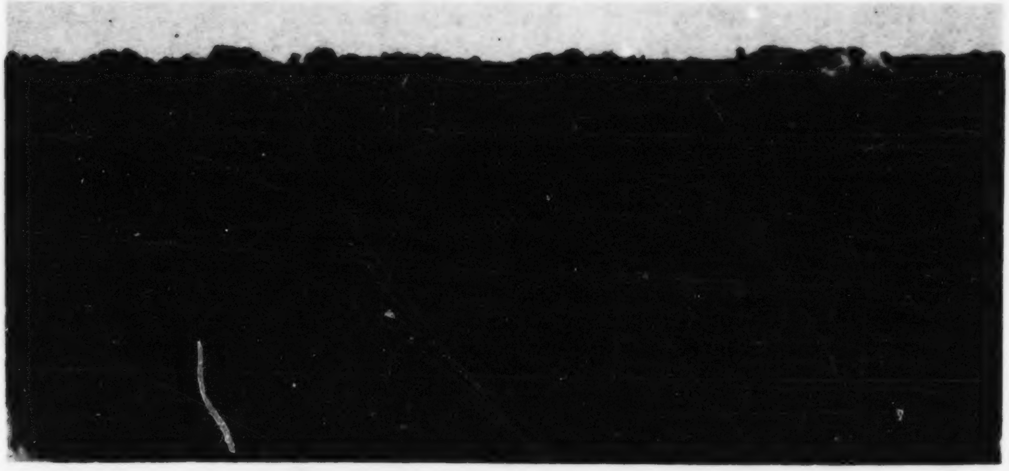

FIGURE 2. GENERAL VIEW OF AN OVERLAND FLOW TREATMENT SITE. (HOEPPEL, HUNT, AND DELANEY[4])

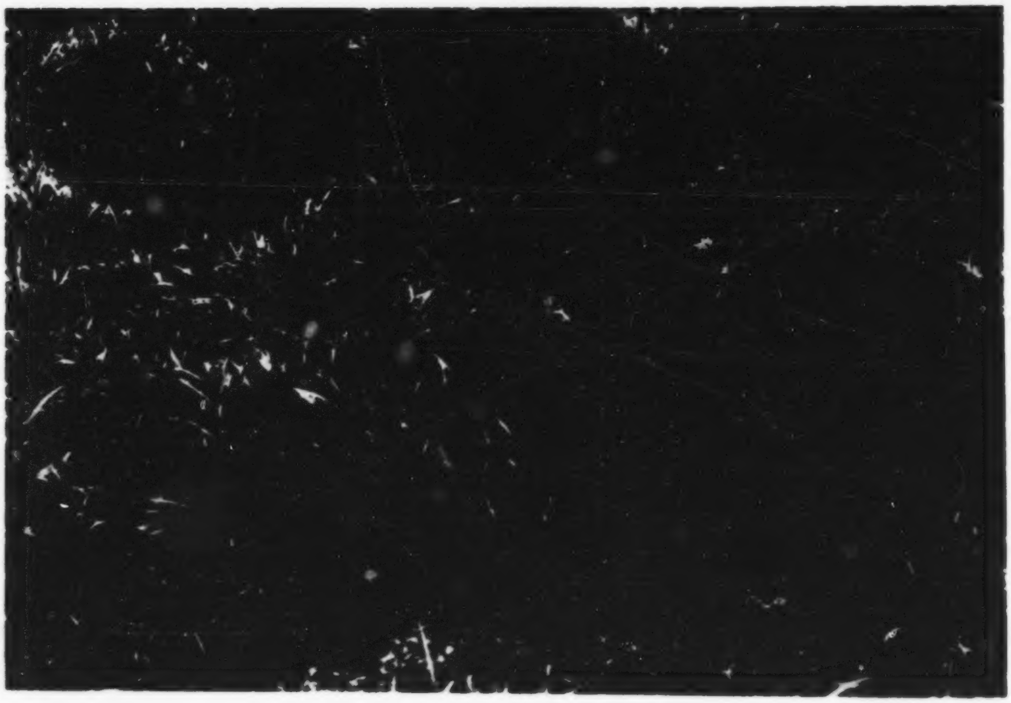

FIGURE 3. CLOSE-UP OF AN OVERLAND FLOW TREATMENT SITE. (HOEPPEL, HUNT, AND DELANEY[4])

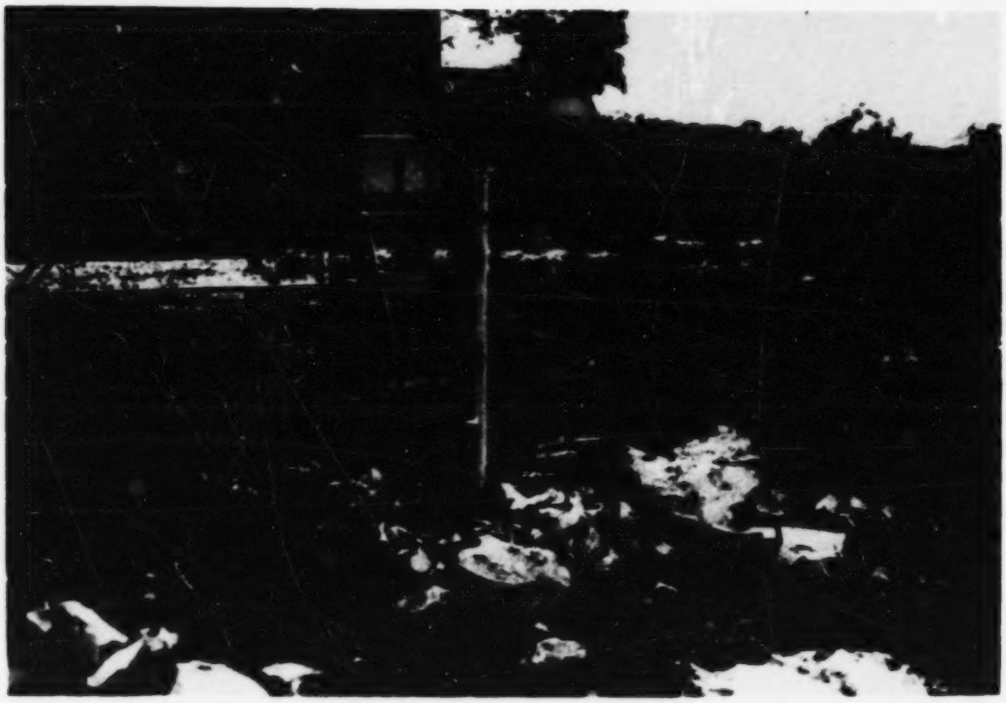

FIGURE 4. WATER-MONITORING SITE FOR TREATED WATER LEAVING THE OVERLAND FLOW TREATMENT SITE. (HOEPPEL, HUNT, AND DELANEY[4])

wastewater and the monitoring station for this system are shown in Figure 4. With overland flow it is possible to have a point discharge from a land treatment system without underdrainage. As with other point discharge systems, the quality of treated wastewater can be easily determined and monitored.

SUPPORT FOR THE FEASIBILITY OF OVERLAND FLOW TREATMENT

Operating Systems

The strongest support for overland flow treatment comes from the Campbell Soup Company's treatment system in Paris, Texas. This system has been operating for ten years in a satisfactory manner.[3] It was shown by an Environmental Protection Agency (EPA) study[6] to have high nitrogen and phosphorus removal as well as very good BOD removal. The reasons for this good wastewater treatment have been somewhat nebulous. In the past, the treatment at Paris, Texas, has been viewed rather lightly and often attributed to rather peculiar conditions that might exist at the site or to physical filtering of the wastewater. It has also been suggested that the wastewater was entering the soil and emerging some number of feet down the slope of the soil. Gaseous loss of ammonia or a trickling filter type of reaction has also been proposed by Hunt.[5] In 1968 it was proposed that nitrogen treatment on such a system was functioning by massive denitrification.[6] This resulted in a controversy that is still not completely resolved. Some of the more penetrating questions that have evolved are how does denitrification, an anaerobic process, occur on the soil surface simultaneously with nitrification and how do plants that require oxygen survive in an anaerobic environment. Initially, these two phenomena seem to be mutually exclusive, but after consideration of the plant, chemical, and biological processes of a rice field or marsh ecosystem, they do not seem so incompatible. These points will be developed more intensively in the section on theoretical support. However, to consulting engineers and city planners, the most impressive facts about the Campbell Soup Company's Paris, Texas, operation are that the system cleans cannery wastewater to better than secondary levels and that it has operated for some ten years in a satisfactory manner from an engineering standpoint.

Research Model Performance

In addition to the Campbell Soup Company's Paris, Texas, system, Thomas[16] has done a considerable amount of research into the treatment of raw and primary wastewater by overland flow. He has generally found the system to give satisfactory treatment of these wastes. However, in 1972, when research was started at the Waterways Experiment Station (WES) on overland flow, there was no experimentation nor use of secondarily treated wastewater in overland flow systems. The initial experimentation at WES was designed to investigate the principles of overland flow treatment and to test the advanced treatment of secondarily treated wastewater by overland flow.

Carlson et al.[2] and Hoeppel et al.[4] have reported on the initial research at WES on overland flow. Their experimentation was conducted on 5- by 10-ft and 5- by 20-ft grass-soil models in a greenhouse. These models were built of plywood and painted with an epoxy conoglaze. Two models were filled to a depth of 6 in. with Susquehanna clay, a kaolinitic soil that is prevalent in the southeast, is high in iron and aluminum, and is low in pH and cation exchange capacity. The soil was placed in these models in 1-in. layers and compacted with a 5-psi weight before the next layer was applied. The models were then sodded with reed canary grass, tall fescue, bermuda grass, and ryegrass. One of the models was constructed on a 2-percent slope, and the other had an adjustable slope of 0 to 10 percent (Figure 5).

A third model, built in a similar manner, was 10 ft long and fixed at a 2-percent slope. The soil and grass for this model were obtained from the spray field at the Campbell Soup Company's Paris, Texas, system in approximately 12- by 12- by 10-in. blocks; transported to Vicksburg, Miss.; and placed into the model.

The wastewater used in these studies had been secondarily treated and chlorinated and normally had nitrogen contents of 14 to 18 ppm of total nitrogen and phosphorus contents of 12 to 14 ppm. The source of wastewater was originally a package treatment plant at a local motel, but wastewater was later obtained from the Vicksburg municipal treatment plant, a trickling filter system, shortly after it was operative in 1974. Concentrations of total nitrogen and phosphorus from the Vicksburg treatment plant have generally been 15 to 20 ppm and 8 to 12 ppm, respectively.

Initially the wastewater applied on the model containing the soil from Paris, Texas, was amended with sucrose to provide an organic carbon source similar to that on the cannery wastewater. This was done to ensure an operating system on which detailed studies could be conducted. Wastewater on the Susquehanna clay model was not amended with sucrose, but it was amended with heavy metals (cadmium, copper, lead, manganese, nickel, and zinc) to simulate a municipal system.

Wastewater was applied at the upper slope of each model at volumes of 0.5 acre-in. per day during a 6-hr application period for five days per week. No wastewater was applied over the weekend. Runoff, subflow, and surface samples of effluent, as well as grass and soil samples, were collected and analyzed periodically.

During this initial 12-week study period, 100, 95, 91, and 75 percent of the ammonium, nitrate, organic nitrogen, and phosphorus, respectively, were removed from the wastewater and retained by the Susquehanna clay model. The model also retained over 90 percent of the trace elements, cadmium, copper, manganese, lead, and nickel, applied in the wastewater. The nitrogen was hypothesized to be removed from the runoff effluent by soil adsorption, plant uptake, and denitrification. Trace element and phosphorus removal from wastewater was hypothesized to have been primarily absorbed by soil and organic matter.

These results from greenhouse model studies are similar to those observed in the field systems in most respects. One of the surprising similarities has been the gradient of grass growth. When overland flow systems are functioning properly, nitrogen will often be stripped from the wastewater before it reaches the collection channel.[6] On such slopes the grass growth responds to the nitrogen concentration and produces a grass-growth gradient. In extreme cases the grass at the lower end of the slope may suffer from lack of nitrogen. Such gradients have not only been observed in our 10- and 20-ft models (Figure 6), but also in 18-in.-long miniature models.

Additionally, treatment efficiency has been found to decrease with increased slope in both field and model studies. Our model studies have generally shown nitrogen treatment to decrease linearly with a geometrical increase of slope between 2 and 8 percent (P.G. Hunt, unpublished data). We believe this to be attributable to decreased residence time of the

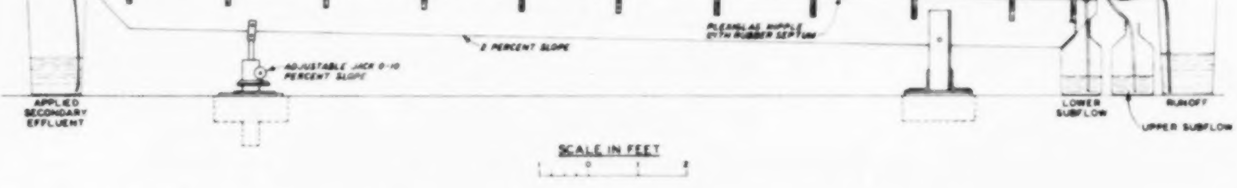
PERISTALTIC TUBE PUMP
TROUGH WITH COVER
PAPER TOWEL WICK
6 IN
CLAY SOIL
FIBERGLASS CLOTH OVER SAMPLING PORT
LEDGE WITH SAND AND FIBERGLASS CLOTH OVER HOLE
TRAY WITH LIP INTO SOIL
SAND ALONG END AND FIBERGLASS CLOTH OVER HOLE
PLEXIGLAS NIPPLE WITH RUBBER SEPTUM
2 PERCENT SLOPE
ADJUSTABLE JACK 0-10 PERCENT SLOPE
APPLIED SECONDARY EFFLUENT
LOWER SUBFLOW
RUNOFF
UPPER SUBFLOW
SCALE IN FEET
1
0
1
2

Figure 5. Longitudinal section of the overland flow wastewater treatment model. (Carlson, Hunt, and Delaney[2])

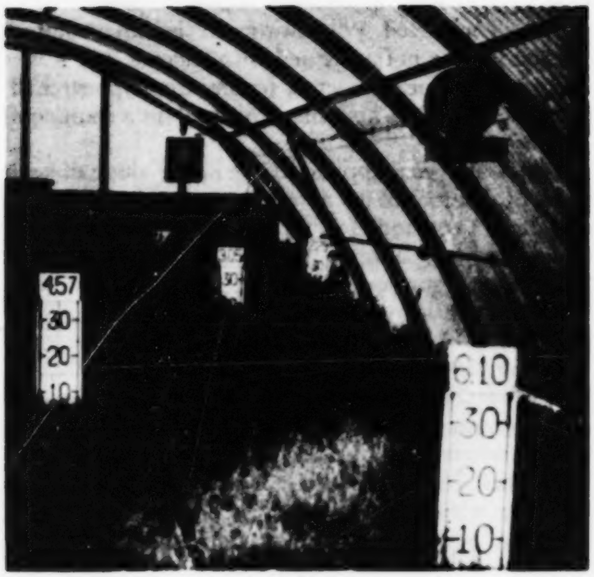

FIGURE 6. WASTEWATER MODEL 43 DAYS AFTER START OF TREATMENT. GRASS HEIGHT REACHED 20 TO 40 CM IN UPPER 10 FT (3.05 M); PRACTICALLY NO INCREASE IN HEIGHT AND ZERO NITROGEN CONTENT IN SURFACE WATER BEYOND 15 FT (4.57 M). (CARLSON, HUNT, AND DELANEY[2])

wastewater on the steeper slopes. This decreased residence time can also be induced by higher application rates, and none of our models have yet been able to treat satisfactorily wastewater applied at a rate of 1 acre-in. during a 6-hr application period. Studies at Pennsylvania State University have shown complete nitrogen treatment failure when very high rates were applied (E.A. Myers, Pennsylvania State University, personal communications).

A significant correlation of both ammonium and nitrate removal to flow rate has been found (Figures 7 and 8). Note that nitrate removal is affected more by flow rate than ammonium removal. In general we have found better nitrogen treatment when the wastewater contained ammonium rather than nitrate nitrogen. The equations of Figures 7 and 8 should not be used for general predictions, since they are limited to the conditions of the model at a particular time during experimentation.

As much as 75 percent of the phosphorus applied in secondary municipal wastewater can be removed by overland flow systems operating at a 2-percent slope with an application rate of 0.5 acre-in. during a 6-hr period. This treatment efficiency has been obtained for approximately ten years at the Campbell Soup Company's cannery at Paris, Texas. The soil has been shown to account for most (69 percent) of the phosphorus removal capacity, while the grass contained a smaller fraction (6 percent) of the phosphorus removed from the wastewater. The key to phosphorus removal from wastewater is contact time and degree of

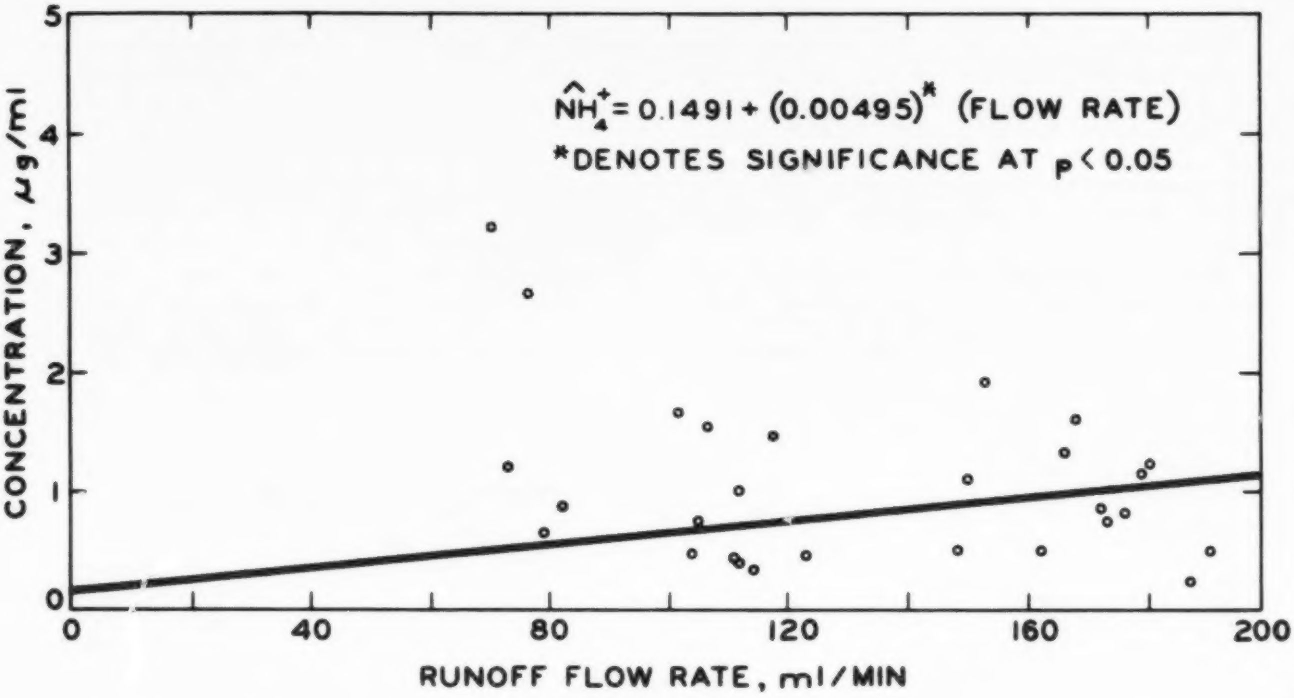

FIGURE 7. SIMPLE LINEAR REGRESSION ANALYSIS FOR NITRATE IN SURFACE RUNOFF. (HOEPPEL, HUNT, AND DELANEY[4])

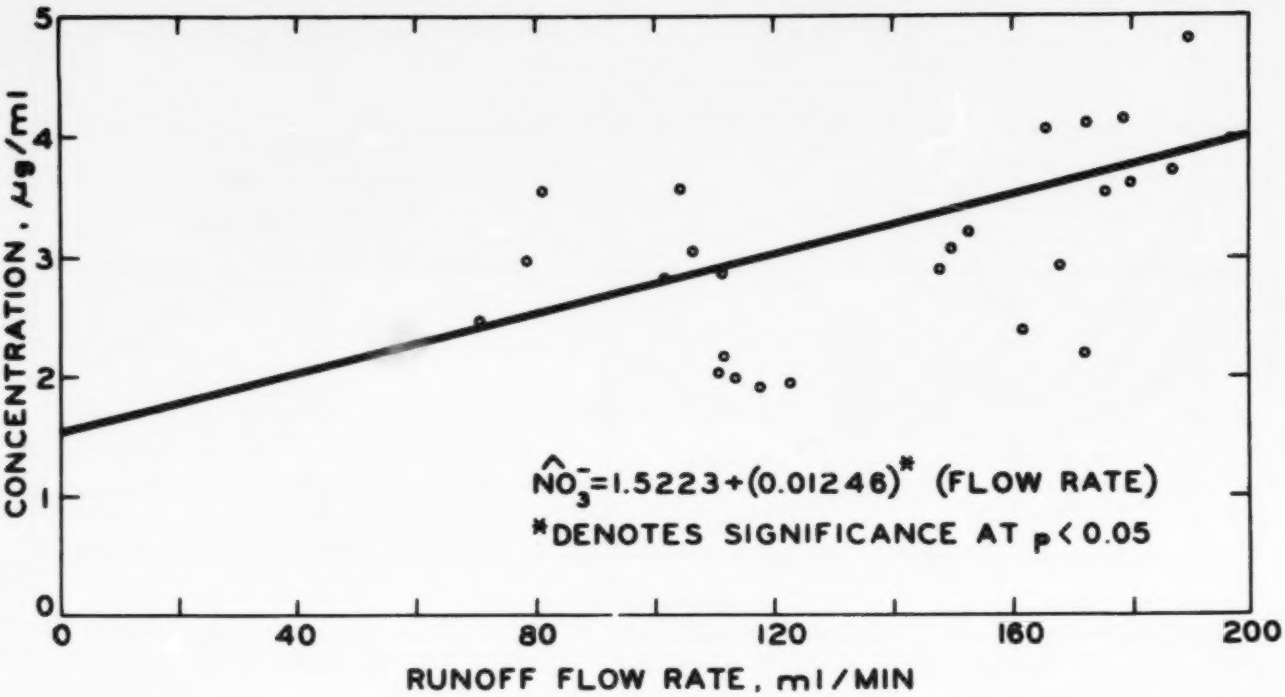

FIGURE 8. SIMPLE LINEAR REGRESSION ANALYSIS FOR AMMONIUM IN SURFACE RUNOFF. (HOEPPEL, HUNT, AND DELANEY[4])

interaction of wastewater with the grass-soil complex. The longer the contact time, the better the phosphorus removal. Applying 0.5 acre-in. of wastewater in 18 hr rather than 6 hr improves phosphorus removal from wastewater to over 80 percent (C.R. Lee, unpublished data); the converse has also been observed. Increasing the volume of wastewater application from 0.5 acre-in. to 1 acre-in. lowers treatment efficiency at both 6- and 18-hr application periods (C.R. Lee, unpublished data).

Another important factor affecting the treatment efficiency of phosphorus removal from wastewater is the slope of the land. At slopes of 2 percent, treatment efficiency has been good with 0.5 acre-in. of wastewater applied in either 6 or 18 hr. Treatment efficiency decreased at slopes of 4 and 8 percent (C.R. Lee, unpublished data). As the slope becomes steeper, smaller volumes of water should be applied and longer application periods should be used. These data again point out the importance of allowing the wastewater to interact sufficiently with the grass-soil complex of overland flow systems in order to remove and fix phosphorus from the wastewater.

Overland flow models effectively removed heavy metals from wastewater. More than 90 percent of the applied heavy metals, such as zinc, manganese, cadmium, nickel, and copper, and as much as 86 percent of the applied lead have been removed from wastewater. Usually these metals are fixed in the soil within 10 ft from the point of wastewater application (Figure 9). No adverse effects on the growth or appearance of grass have been observed for the past two years of treatment on greenhouse models.

However, the heavy metals appear to be held in the surface organic layer (C.R. Lee, unpublished data). Their concentration in this layer may become a problem after a period of time. One obvious way in which the concentration of heavy metals in the surface organic mat could be reduced would be by plowing the layer into the soil. Additionally, the authors believe that a considerably better job of point source control of heavy metals would greatly reduce their concentration in secondarily treated wastewater. Further research into the long-term fate of heavy metals in overland flow systems and the best methods of managing the system for heavy metals is needed.

Theoretical Support

The treatment of nitrogen by overland flow in both models and field studies has been good. There have apparently been considerable losses of nitrogen to the atmosphere through denitrification. Initially this is a hard statement to believe. It would appear that the soluble nitrate and ammonium nigrogen would move rapidly over the surface without treatment. However, the most paradoxical question is how does denitrification (a distinctly anaerobic process) and nitrification (a distinctly aerobic process) occur on the soil surface or within the surface water simultaneously? As a result of this paradox, many engineers and scientists

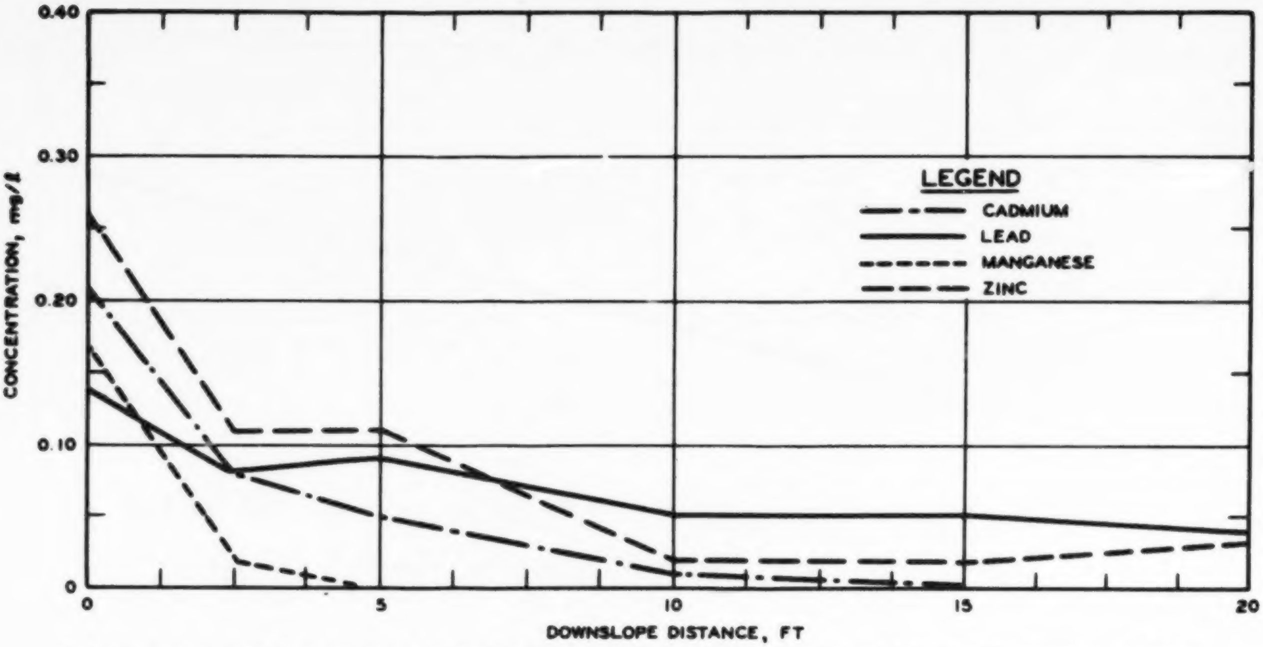

FIGURE 9. HEAVY-METAL CONCENTRATIONS IN SURFACE WATER FLOWING OVER SUSQUEHANNA CLAY. (CARLSON, HUNT, AND DELANEY[2])

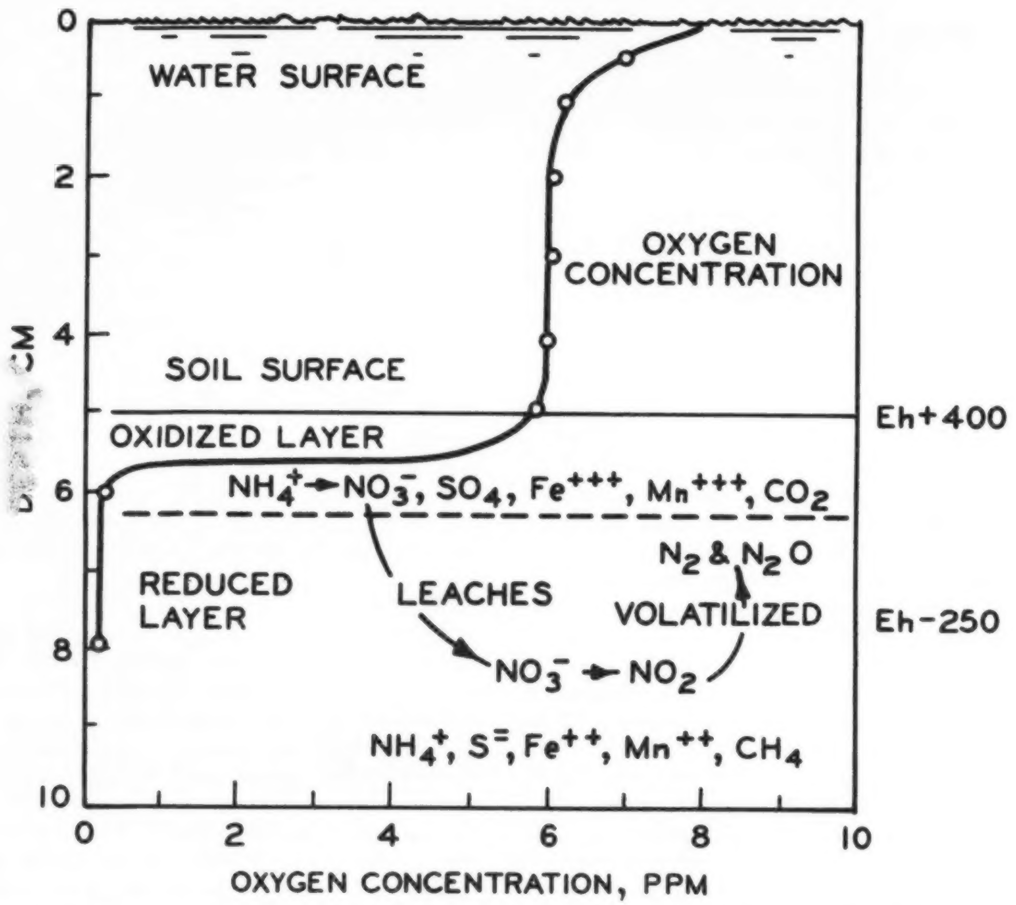

FIGURE 10. OXYGEN PROFILE IN FLOODED SOIL. (AFTER PATRICK AND MIKKELSEN[7]) (REPRINTED FROM *FERTILIZER TECHNOLOGY AND USE*)

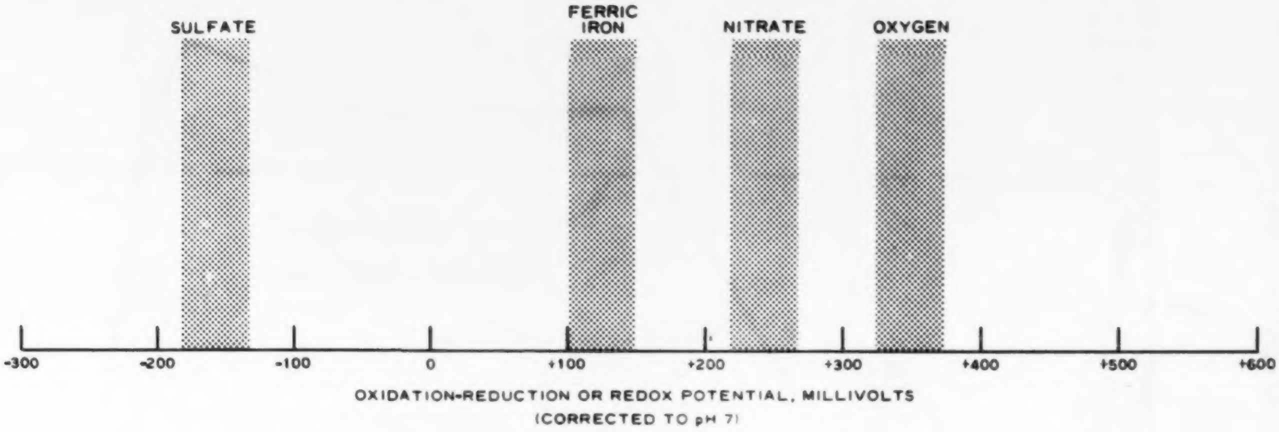

FIGURE 11. RANGE OF REDOX POTENTIALS AT WHICH SELECTED CHEMICALS DOMINATE THE SYSTEM. (AFTER PATRICK AND MIKKELSEN[7]) (REPRINTED FROM *FERTILIZER TECHNOLOGY AND USE*)

have dismissed overland flow as something slightly less than a hoax.

It is the authors' hope that the following theory of overland flow treatment will enable the reader to understand how an overland flow system functions rather than simply to accept it in a type of religious faith in Mother Nature's processes. It is also hoped that the information and evidence will be convincing enough that planners, consultants, and concerned groups will make realistic assessments of the possibility of treating wastewater on soil of low permeability.

It is the authors' view that overland flow systems function chemically and biologically in a manner quite similar to a flooded rice field. The chemistry of soils under rice cultivation has been studied extensively.[9] The schematic of Patrick and Mikkelsen[7] presented in Figure 10 is quite good for our discussion. If one follows the oxygen concentration curve at the top of the figure, there is an initial drop in oxygen concentration at the water surface due to the reduced diffusion rate and increased oxygen demand. At the soil surface and in the oxidized layer, there is another drop in oxygen concentration associated with the increase in oxygen demand of microorganisms and a more tortuous diffusion path. At some depth in the soil, depending upon the oxygen demand, soil texture, and duration of flooding, the oxygen concentration approaches zero. In an overland flow system, the depth at which oxygen is absent may be only a fraction of a millimeter.

Once the system has consumed the oxygen, a good measure of the chemical state of the system is the oxidation-reduction potential, Eh. In Figure 10 the Eh is shown to be above +400 mv when oxygen is present and to drop to -250 mv with depth after the oxygen is consumed. According to numerous studies, Eh can tell us a great deal about the condition of a soil. The system is particularly well presented by Patrick and Mikkelsen[7] (Figure 11). In this figure the Eh of a system is presented as being dominated and poised by a particular chemical and remaining poised at the potential of that chemical until it is consumed. In this case it is shown that the nitrate ion poises the Eh at approximately +250 mv. When NO^3 is consumed, the potential is dominated by Mn^{+3}, Fe^{+3}, and SO_4^{-2}, respectively. It is both interesting and fortunate that the SO_4^{-2} to S^{-2} conversion occurs under rather harsh reducing conditions. Thus the oscillation of flooded and drying conditions minimizes the reducing conditions, Eh drop, and the odors associated with sulfur under reduced conditions.

Figure 12 illustrates the results of an Eh monitoring of one of our greenhouse models. The plotted values are means of ten locations. Two very interesting facts were discovered. First, if the value of +320 mv is used as the unstable point for nitrate at pH5, the model is definitely under excellent denitrifying conditions at the 5-mm depth during wastewater application periods. These denitrifying conditions could easily exist at a fraction of a millimeter into the soil or in the organic layer. Second, during the drying period, the Eh rose above the nitrate potential into the oxygenated region at the 5-mm depth and became more oxidized at the 13-mm depth. It is also interesting that upon application of wastewater, the Eh dropped rapidly into the denitrifying area. Proof of the existence of an overlying aerobic zone is found in the fact that nitrification in the flowing wastewater proceeds at a rapid pace even when highly reduced conditions exist at 5-mm soil depth.

In order to verify the Eh responses in an overland flow system, we went to the Campbell Soup Company's Paris, Texas, plant to conduct a field experiment. In that study we monitored two spray areas at three distances down the slope and three soil depths at each location. Measurements were made five times per day for two weeks. The data from this study are un-

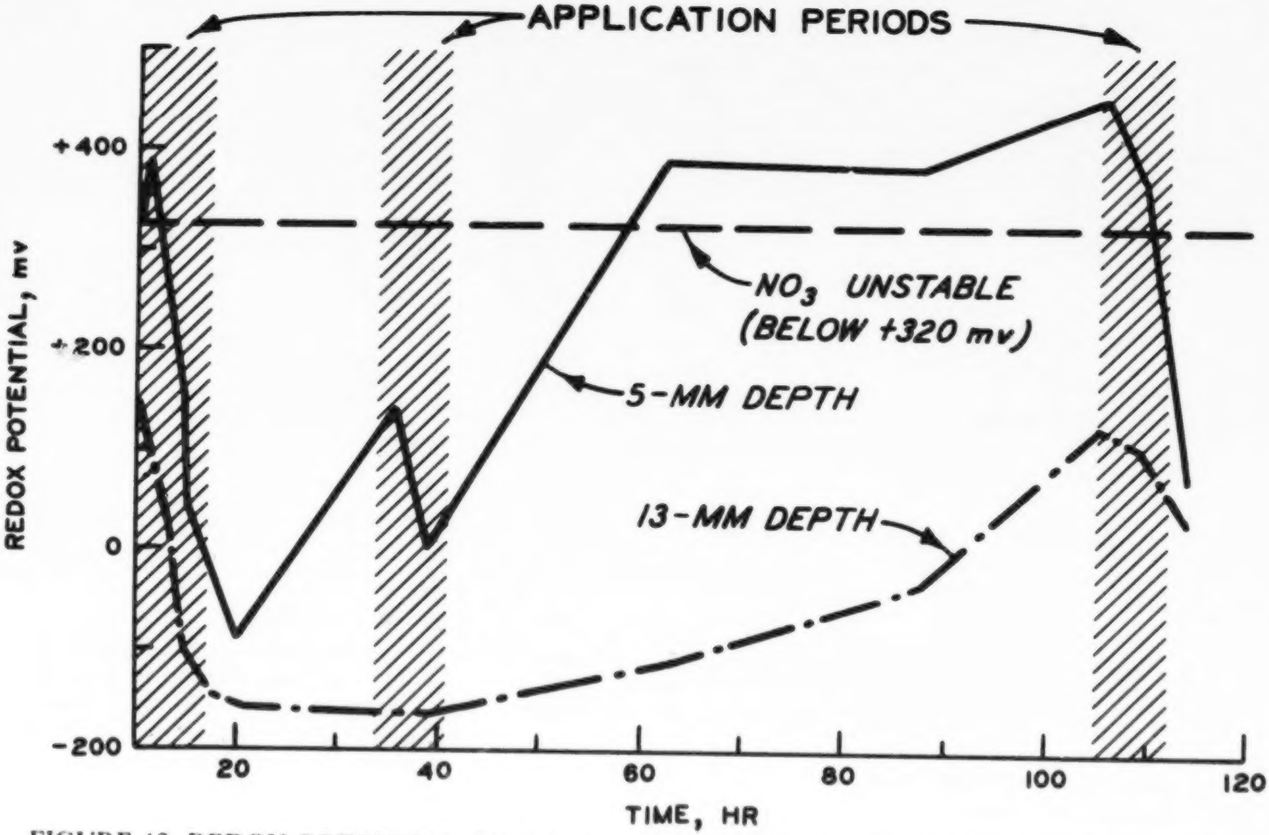

FIGURE 12. REDOX POTENTIAL OF THE SUSQUEHANNA CLAY DURING A WASTEWATER APPLICATION-DRYING CYCLE. (CARLSON, HUNT, AND DELANEY[2])

published at this time. However, it can safely be said that the condition of the soil on this system was under denitrifying conditions during wastewater application periods. With allowances for precipitation, it can also be said that the system generally oscillated between oxidized and reduced conditions similar to that observed on our greenhouse models.

Instead of the "aerobic-anaerobic double layer" theory, it might be conjectured that an overland flow system functions similarly to a trickling filter, with the exception that flow is horizontal rather than vertical. In such a system, the algal mat that sometimes forms on the soil surface would be important. However, experience at the Campbell Soup Company's overland flow system in Paris, Texas, has shown algal mats to be detrimental (Mr. Charles Neely, Campbell Soup Company, Paris, Texas; personal communication). Additionally, algal mats have been found to decrease nitrogen treatment efficiency in model studies at the WES.[4]

In an algal mat study, grass on one-half of a 5- by 10-ft model containing soil from the Campbell Soup Company's Paris, Texas, system was cut and maintained at a low enough height to allow an extensive algal mat to form. The mat was maintained for approximately six weeks. During this time the treatment efficiency for nitrogen decreased on the side covered with algal growth. A very puzzling point concerning this reduction in treatment was that both nitrate and ammonium were flowing across and off the models. This was unexpected because ammonium should have been nitrified to nitrate if the soil was too oxidized and nitrate should have been removed through denitrification if the system was too reduced. It might be said that the system was simultaneously failing from both directions.

A hypothesis of what was occurring on the model and why algal mats are detrimental to overland flow systems is illustrated in Figure 13. The algal mat is hypothesized to act as a physical barrier against the free diffusion between the aerobic-anaerobic layers. Above the mat nitrogen is pushed to the nitrate form through mineralization and nitrification. The nitrate then flows on the surface of the algal mat and off the model. Below the algal mat the nitrate is denitrified, but very little nitrogen reaches the nitrate form because the anaerobic conditions block nitrification and the algal mat barrier blocks the free diffusion of nitrate. In such a combination, ammonium accumulates, moves down the slope under the algal mat, and flows off the system. Failure of the system in this manner supports the "aerobic-anaerobic double layer" theory that both aerobic and anaerobic zones coexist and that diffusion between them is free in operating overland flow systems.

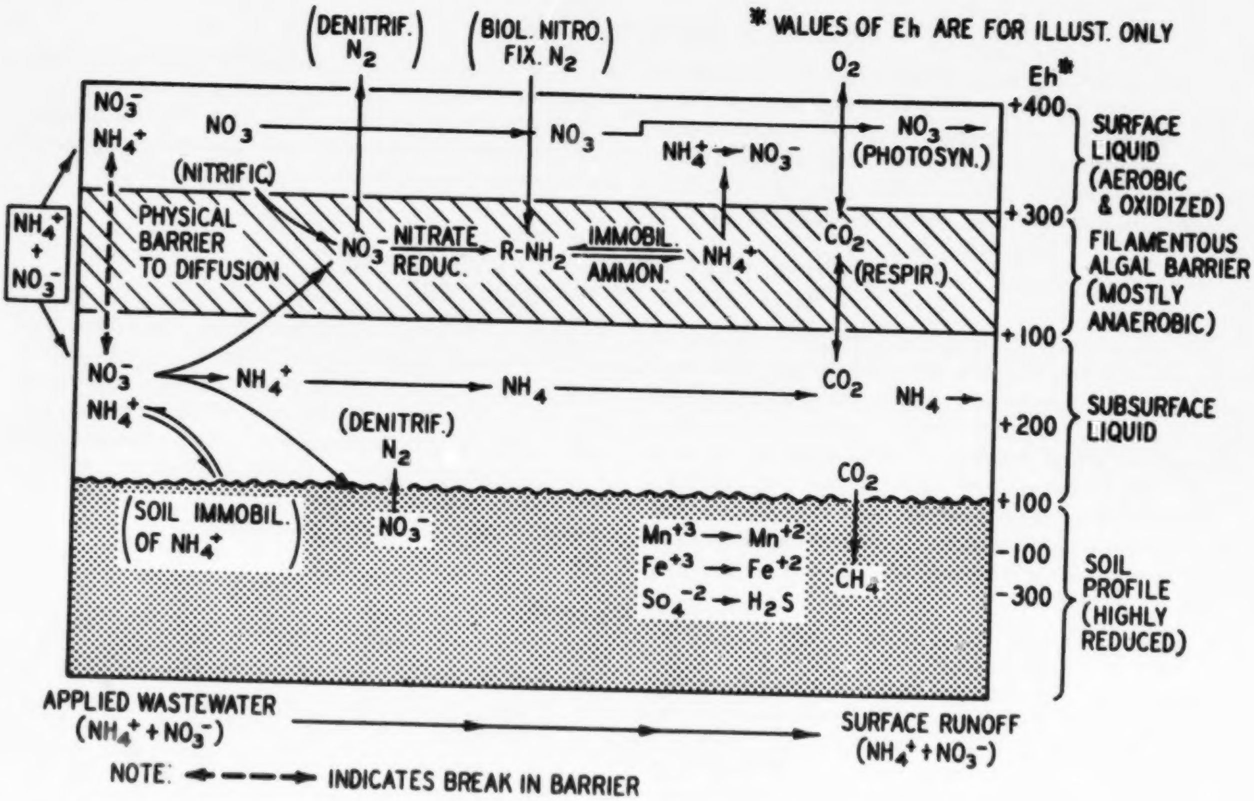
(DENITRIF. N2)
(BIOL. NITRO. FIX. N2)
* VALUES OF Eh ARE FOR ILLUST. ONLY
O2
Eh*
NO3-
NH4+
NO3
NO3
NO3
NH4+ → NO3-
(PHOTOSYN.)
(NITRIFIC)
+400
SURFACE LIQUID (AEROBIC & OXIDIZED)
NH4+ + NO3-
PHYSICAL BARRIER TO DIFFUSION
NO3- NITRATE REDUC. R-NH2 IMMOBIL. AMMON. NH4+
CO2
(RESPIR.)
+300
FILAMENTOUS ALGAL BARRIER (MOSTLY ANAEROBIC)
+100
NO3-
NH4+
NH4+
NH4
CO2
NH4
(DENITRIF.) N2
+200
SUBSURFACE LIQUID
CO2
+100
(SOIL IMMOBIL. OF NH4+)
NO3-
Mn+3 → Mn+2
Fe+3 → Fe+2
SO4-2 → H2S
CH4
-100
-300
SOIL PROFILE (HIGHLY REDUCED)
APPLIED WASTEWATER (NH4+ + NO3-)
SURFACE RUNOFF (NH4+ + NO3-)
NOTE: ←---→ INDICATES BREAK IN BARRIER

FIGURE 13. CROSS SECTION OF A FLOODED SOIL. (HOEPPEL, HUNT, AND DELANEY[4])

APPARENT OPERATIONAL AND DESIGN PROBLEM AREAS FOR OVERLAND FLOW

One of the first considerations in building an overland flow system is to obtain a slope that will allow sufficient residence time to provide adequate treatment. Generally slopes less than 8 percent are required. In addition, the slope surface must be smooth to allow for the uniform flow of wastewater over the soil surface. Unfilled channels cause treatment problems and may start erosion. To obtain these slopes and surface conditions, considerable earthwork may be necessary. The overland flow system used by Campbell Soup Company in Paris, Texas, for instance, has had both timber clearing and soil cut-and-fill operations in its construction. Insufficient preparation of an overland flow treatment site is no less a problem than underdesign of a settling basin or clarifier in a standard treatment plant.

Since a cover crop is an integral part of the overland flow treatment and an erosion retardant, a good vegetative cover is essential. Reed canary grass has been used most extensively on overland flow systems and at present appears to be the best all-around cover crop. However, the major characteristic that the cover crop must have is the ability to live in a reduced wet soil profile. Many plants such as rice are capable of transporting oxygen from their leaves to their root systems and are thus able to live quite well in reduced soils. Whether or not this is the mechanism whereby reed canary grass survives in a reduced soil is of academic interest for this report. It can be very confidently stated, however, that a plant that requires an aerobic soil profile will not be an adequate cover crop for an overland flow system.

Cold weather is another serious concern. Microbial processes are a significant component in overland flow processes, and their rates are reduced under cold conditions. The formation of ice will most definitely adversely affect treatment performance, and a reservoir may be necessary to hold wastewater during the adverse weather periods.

Even with the proper soil preparation, plant cover, and weather conditions, the most common mistake made on land treatment of wastewater systems probably is either hydraulic or chemical overloading. Overland flow systems are slow rate systems; volumes of greater than 1/2 acre-in. per day have generally been found unsatisfactory. In addition, the rate at which a given volume of wastewater can be treated each day will vary with slope and other factors that affect treatment efficiencies.

COST OF OVERLAND FLOW SYSTEMS

Cost of overland flow systems has been cited by Gilde et al.[3] at approximately $1000 per acre in 1969. More recent figures suggest a cost of approximately $2000 per acre (Charles Pound, Metcalf and Eddy, personal communications). However, for further detailed information the reader is referred to Mr. Pound's chapter in this manuscript and to an EPA report on the cost of land treatment systems by Metcalf and Eddy that will be released in 1975 for detailed cost figures for overland flow and other forms of wastewater treatment via land application.

PRESSING NEEDS FOR OVERLAND FLOW TREATMENT OF WASTEWATER

The major need for public acceptance and use of overland flow treatment is the construction of several demonstration systems in various parts of the United States. These systems would provide the data necessary to refine designs and make them less conservative and, thereby, more cost effective. The authors would hasten to add, however, that even the conservative designs may be more cost effective than many other types of advanced wastewater treatment systems. Therefore, administrators, engineers, and scientists should seriously consider the land application system that suits their particular soil conditions, even if their soils are sloped and of low permeability. They should also bear in mind that overland flow systems, just like lagoons, trickling filters, or rapid infiltration systems, function properly when they are designed on operational principles.

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Infiltration-Percolation Systems

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INTRODUCTION

Infiltration-percolation systems, commonly called high-rate systems, are land treatment systems whereby municipal or other wastewater is applied at much higher rates (0.3 to 3 m or 1 to 10 feet per week) than with low-rate or irrigation-type systems where only about 2 to 8 cm (1 to 3 inches) per week are applied. High-rate systems require relatively permeable soil, such as sandy loams to medium sands. The transmissibility of the underlying aquifer should also be sufficiently high to conduct the water laterally away from the infiltration area without undue water-table rises.

An obvious advantage of high-rate systems is the low land requirement, which is only 1 to 10% of that for low-rate systems. Because of this, the land normally is not used for growing crops and its primary function is to receive and renovate wastewater. The effluent is usually applied with basins or furrows. Application by sprinklers requires additional pumping. Also, the frequent, intermittent application (once every sprinkler revolution) obtained with rotating sprinklers may not be desirable for stimulating denitrification in the soil.

Another advantage of high-rate systems is that the infiltration rates are much higher than the (potential) evapotranspiration rate. Thus, the salt content of the renovated water is only slightly higher than that of the original wastewater. This is of importance in warm, arid regions where the main purpose of land treatment is to produce renovated water for unrestricted irrigation, primary-contact recreation, and industrial or other purposes. For example, if the evapotranspiration rate is 1.8 m (6 ft) per year and the wastewater application is 3.6 m (12 ft) per year, the salt concentration of the renovated water will be twice that of the wastewater. However, if 60 m (200 ft) of wastewater are applied per year, the salt concentration of the renovated water will only be 3% more than that of the wastewater (assuming uniform application over the year and neglecting rainfall, precipitation or dissolution of salt in the soil, and other factors which have a minor effect on the salt balance).

Because of the high hydraulic loading rates in high-rate systems, the amounts of nitrogen, phosphorus, and other elements entering the ground with the wastewater are much higher than a crop could remove. Thus, special management techniques are required to stimulate denitrification of nitrate and immobilization of phosphate in the soil to yield renovated water of acceptable quality. High hydraulic loading rates still yield complete removal of the biochemical oxygen demand, suspended solids, and the micro-organisms, at least for secondary effluent that is applied to soils that are not too coarse and have no cracks or other large pores.

While the quality of the renovated water is much better than that of the original wastewater, it may not be as good as that of the native groundwater. Thus, it may be desirable to restrict the spread of renovated water into the groundwater basin. This can be accomplished by selecting the site for the infiltration system so that the renovated water naturally drains into surface water. Where this is not possible, wells or drains can be installed to artificially remove the renovated water from the aquifer. The renovated water can then be discharged into surface water or it can be reused.

More detailed discussions of the various aspects of high-rate land treatment systems for secondary sewage effluent and other wastewater are presented in the following sections. The paper concludes with a few general remarks, including economic aspects and the selection of land treatment as a solution to a wastewater management problem.

HYDRAULIC LOADING RATE

A key soil factor in designing a high-rate land treatment system is the final infiltration rate, which can be measured with large cylinder infiltrometers. The final infiltration rate obtained in this manner will be reasonably accurate if the soil is uniform to great depth or if there is a restricting layer at or near the surface. If continuous restricting layers occur in the zone above the water table at depths of about 10 cm (4 in.) or more, cylinder infiltrometers may seriously overestimate the final infiltration rate. In that case, the final infiltration rate can be more accurately calculated from measurements of the vertical hydraulic conductivity of the individual soil layers.

The long-term hydraulic loading rate for wastewater is much less than the final infiltration rate for clear water because (1) suspended solids and biological activity clog the surface of the soil, and (2) infiltration periods must be alternated with drying (resting) periods to aerate the soil and to allow the clogging material on the surface to dry and decompose for infiltration recovery.

The optimum application schedule must be determined for each site, since it depends on the soil and climatic conditions as well as on the characteristics of the wastewater. The schedule giving the highest hydraulic loading rate may not yield the highest quality renovated water. Thus, there may be a trade off between quantity and quality of renovated water obtained. Application schedules may range from 8 hours infiltration and 16 hours drying to infiltration and drying periods of several weeks each.

At the Flushing Meadows Project near Phoenix, Arizona (Bouwer et al.[1]), optimum flooding periods are 10 to 14 days and drying periods range from about 10 days in the summer to 20 days in the winter. The final infiltration rate for clear water at the Flushing Meadows Project is about 1.2 m (4 ft) per day. During flooding, the average infiltration rate for secondary sewage effluent is about 0.6 m (2 ft) per day. Since the basins are flooded only about one-half the time, the average long-term hydraulic loading rate is about 0.3 m (1 ft) per day, or one-fourth the final infiltration rate for clear water. Lower ratios of hydraulic loading to final infiltration rate may occur in temperate or humid regions where longer drying periods may be needed for infiltration recovery. The ratio also is affected by the quality of the effluent. For example, the suspended solids content of the effluent should be well below 20 mg/liter to avoid serious clogging problems (Rice[2]). Also, the higher the BOD, the more clogging can be expected from biological activity.

QUALITY IMPROVEMENT

Nitrogen

Assuming a total nitrogen content of 25 mg/liter in the effluent, 25,000 kg of nitrogen enter the soil per ha with every 100 m of effluent applied (20,400 pounds of N per acre with every 300 ft of effluent). This is much more than the 50-600 kg/ha or pounds/acre that can be removed by crop uptake. To remove more nitrogen, denitrification in the soil must be stimulated. This is achieved by managing the system to bring nitrate and organic carbon together in the soil under anaerobic conditions.

For the Flushing Meadows Project, denitrification was maximum if flooding periods were about 10 days and drying periods about 2 weeks. With this schedule, oxygen in the soil was soon depleted during flooding so that nitrogen, which was mostly in the ammonium form in the secondary effluent, was adsorbed to the clay and organic matter in the soil. Flooding was stopped before the cation exchange complex was saturated with ammonium. Oxygen then entered the soil, causing aerobic conditions and permitting nitrification of the adsorbed ammonium. Drying periods must be sufficiently long to insure that all nitrogen that was adsorbed as ammonium in the soil during flooding will be converted to nitrate during drying (Lance et al.[3]). Some of the nitrate thus formed was denitrified in micro-anaerobic environments in the otherwise aerobic upper few feet of the soil (Gilbert et al.[4]). The remaining nitrate then was leached out when flooding was resumed, causing a nitrate peak in the renovated water (Bouwer et al.[5]).

Some denitrification probably also occurred as the nitrate mixed with the newly infiltrated sewage effluent while it was leached out. If the newly applied sewage effluent entered the soil at high infiltration rates (due to a depth of flooding of about 0.3 m (1 ft) in the basins, for example), the nitrate was leached out rather rapidly. Thus, there was not much time for denitrification and the total nitrogen removal was only about 30%. If, however, the newly applied effluent was allowed to enter the soil at a lower infiltration rate (by reducing the depth of flooding in the basin to a few inches) the nitrates were not leached out as rapidly and spent more time in the microbiologically active upper portion of the soil while mixing with the effluent. This increased denitrification, which reduced the nitrate peaks and yielded total-N removals of as much as 80%. Lance et al.[6] reported an exponential increase in nitrogen removal with decreasing hydraulic loading rate.

The flooding schedule and desired infiltration rates for maximizing denitrification depend on the cation exchange capacity of the soil, the ammonium exchange percentage, the nitrogen content of the wastewater, the oxygen diffusion rate into the soil during drying, the temperature, and other factors. Thus, the optimum schedule for denitrification must be developed for each particular system. While it is possible to estimate this schedule from theory, field testing different schedules will usually be needed because of the numerous factors involved.

Essentially no nitrogen was removed at the Flushing Meadows Project if short, frequent flooding periods (about 2 days flooding alternated with 5- to 10-day drying periods) were used. Apparently, the soil profile was predominantly aerobic with this schedule, and effluent N was essentially completely converted to nitrate. A similar situation can be expected when the effluent is applied with rotating sprinklers (Smith[7]). On rapidly draining soil, enough oxygen may enter the soil in the short time between sprinkler revolutions to maintain aerobic conditions, regardless of the length of the application period. Also, no nitrogen will be removed if the flooding periods are excessively long. The resulting lack of oxygen in the soil will prevent nitrate formation. The cation exchange complex will then become saturated with ammonium, allowing ammonium to pass through and remain in the renovated water.

Phosphorus

Assuming a phosphorus content of 10 mg/liter in secondary sewage effluent, 10,000 kg of P would enter the soil per ha for every 100 m of effluent applied (2,720 pounds per acre per 100 ft effluent). Compared with this amount, the uptake of P by plants is negligible. Thus, the only mechanism for removing P from the effluent water, as it moves downward through the soil, is precipitation of P. Phosphate may be adsorbed first and then revert to insoluble compounds. This reversion occurred during drying periods due to reaction between adsorbed phosphate and iron and aluminum oxides released in the soil by weathering (Beek and de Haan[8]). Because adsorbed phosphate can gradually change to insoluble forms, many soils can store more P than indicated by quick adsorption tests.

Other insoluble P compounds are complex calcium magnesium phosphates, such as apatites, and magnesium ammonium phosphate. Apatites are formed in the soil if the pH is on the alkaline side and if sufficient calcium and magnesium are present in the effluent or in the soil. Underground travel distances for the renovated water of at least 100 m (several hundred feet) may be necessary to obtain P-removals of 90% or more (Bouwer et al.[5]). Under certain soil conditions, for example relatively pure sand and a pH below 7, phosphate may be more mobile. Then, phosphate could be removed prior to infiltration by adding lime, alum, iron chloride, or other precipitant to the effluent.

Minor Elements

Metals, boron, fluorine, and other elements present in small concentrations in the wastewater may accumulate in the soil or remain in the renovated water, depending on the element and soil conditions. At the Flushing Meadows Project, copper, zinc, and fluoride accumulated in the soil, but cadmium, lead, and boron occurred in approximately the same concentration in the renovated water as in the secondary effluent (Bouwer et al.[5]). About one-half of the mercury remained in the soil. Different results may be obtained with other soils. For example, soils containing clay or aluminum and iron oxides will immobilize more boron than sandy soils. Large, stable organic molecules may act as chelating agents, thus increasing the mobility of metals in the soil and in the aquifer.

Since most of the metals in sewage end up in the sludge, the metal concentrations in the effluent are usually quite low and below maximum limits suggested for drinking water. Excessive concentrations of minor elements in sewage effluent may be caused by industrial discharges or by the use of certain household products (boron) and can best be controlled at the source.

Organic Carbon

The BOD of the renovated sewage water from high-rate land treatment systems is essentially zero. However, like most other tertiary treatment processes, some organic carbon tends to remain in the renovated water. The concentration of this refractory organic carbon in the renovated water averaged about 4 mg/liter for the Flushing Meadows Project (Bouwer et al.[5]). Some of this carbon may be due to lignin or humus-like compounds (humic or fulvic acids). More work is needed on identifying the refractory organics, however. Renovated water is guilty until proven innocent, and as long as unidentified organic carbon is known to be present, an uncertainty remains regarding use of this water for drinking or domestic purposes.

Bacteria and Viruses

Evidence is accumulating that sufficient distance of movement through relatively fine soil without large pores or other short-circuiting passages effectively removes all micro-organisms. At the Flushing Meadows Project, fecal coliforms were reduced from about 10^6 to generally less than 200 per 100 ml after 9 m (30 ft) of downward movement. Additional lateral travel further reduced the coliform density to generally less than 10 per 100 ml after 30 m (100 ft) and to zero after 90 m (300 ft) (Bouwer et al.[5]).

A program of concentrating large samples (several hundred liters) of renovated water for virus assay was begun at the Flushing Meadows Project in January 1974 in cooperation with the Virology and Epidemiology Department of Baylor College of Medicine, Houston Texas. So far, virus has not been detected in any of the renovated water samples, which were collected bimonthly. A more detailed report will be prepared by the investigators directly involved.

CONTROL OF UNDERGROUND FLOW

Undesirable spread of renovated water into the groundwater basin can be avoided by locating the infiltration facilities so that renovated water either drains naturally into surface water, or is intercepted with horizontal drains if the aquifer is shallow and with wells if the aquifer is deep. The systems must be designed so that renovated water has had sufficient underground detention time and has moved a sufficient distance underground to be of suitable quality when it leaves the aquifer. The proper time and distance needed depend on the quality of the effluent, the desired quality of the renovated water, the application rate, and the soil and aquifer materials. Generally, movement through about 100 m (several hundred feet) of granular soil and aquifer material with no macropores, cracks, fractures, or other large openings, and an underground detention time of about a month may be sufficient to yield "safe and polished" renovated water. Most of the quality improvement, however, takes place in the first meter (3 feet) of the soil profile, especially when biochemical reactions are involved (Bouwer et al.[5], Gilbert et al.[4]).

There are different opinions regarding the optimum depth of the groundwater table. While some persons advocate depths of at least 3 m (10 ft), shallower water tables may not be objectionable. If infiltration periods longer than 2 or 3 days are employed, the oxygen in the soil will be essentially depleted. Thus, from an aeration standpoint, high water tables below rapid infiltration systems are of no concern, except for the initial flooding stages. Water table rises so high that they restrict the infiltration rate should be avoided, however. Since most of the head due to water depth in infiltration basins is dissipated because of surface clogging within the first few cm (1 or 2 in.) of soil, the water table generally will not affect the infiltration rate until it reaches essentially the surface of the soil. Thus, water table rises to within 15 cm (6 in.) of the soil surface can usually be tolerated during flooding. However, after infiltration is stopped to start a drying (resting) period, a rapid fall of the water table is desirable to quickly aerate the soil. Since the oxygen diffusion rate slows considerably at depths of about 1 m (3 ft), depending on the soil and on the soil water content after drainage (Lance et al.[3]), a water table depth of about 1.5 m (5 ft) during drying seems adequate. Deeper water tables would not materially increase the depth of the aerobic zone during drying.

Natural Drainage into Surface Water

When renovated water is allowed to drain into surface water (Figure 1), care should be taken that the aquifer can transmit the flow of renovated water without undue water table rises below the infiltration areas. This can be checked with the approximate equation

$$WI = KDH/L \qquad (1)$$

where W = width of infiltration area (m)
I = hydraulic loading rate or average infiltration rate for the infiltration system (m/day)
K = hydraulic conductivity of aquifer (m/day)
D = average thickness of zone below water table perpendicular to flow direction (m)
H = elevation difference between water level in stream or lake and maximum allowable water table level below infiltration area (m), and
L = distance of lateral flow (m).

If there is already a water table in the system and natural drainage of groundwater to the surface water already takes place, the magnitude of the drainage flow can be calculated by substituting the "natural" values of D and H in the right half of equation (1). The resulting flow rate is then added to WI when applying equation (1) to the effluent-infiltration system (see "Example").

Equation (1) shows that the product, WI, is the important parameter of the infiltration system. Where underground flow is restricting WI, high values of I can still be used if W is taken proportionally smaller. This results in long, narrow infiltration areas normal to the slope.

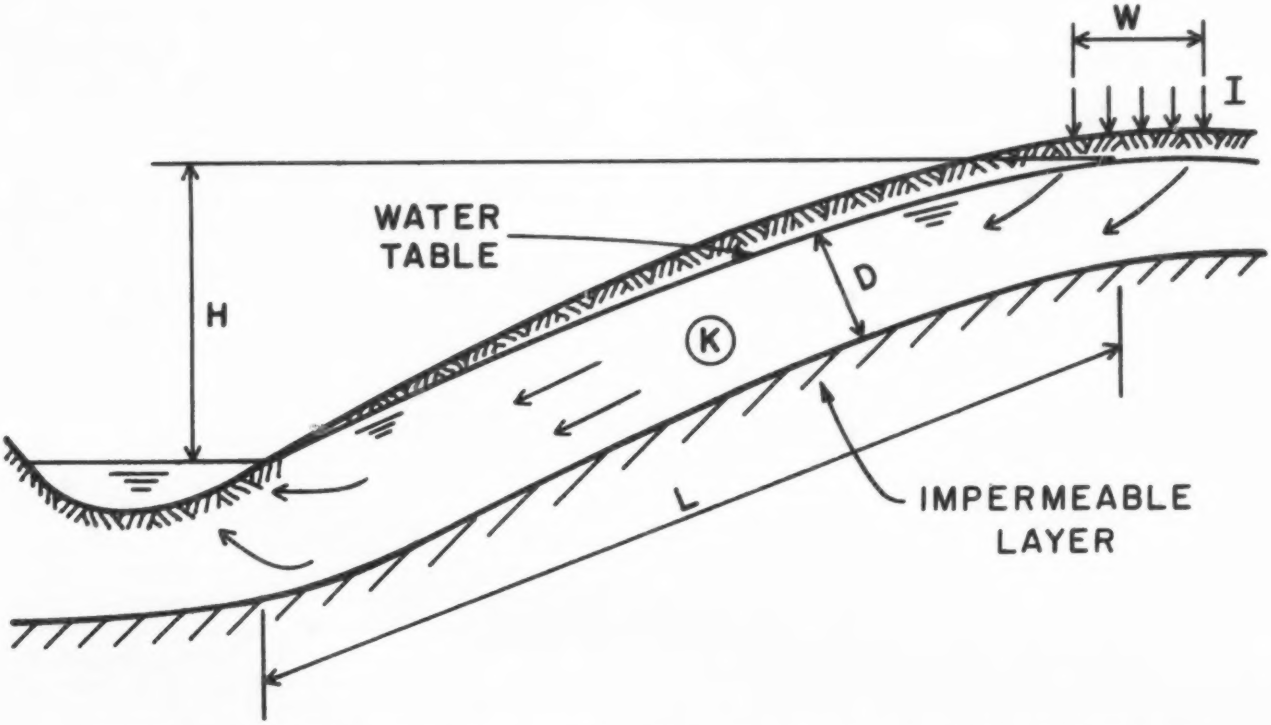

FIGURE 1. NATURAL DRAINAGE OF RENOVATED WATER INTO SURFACE WATER.

Example –

Sewage effluent is to be applied to an "infiltration strip," which parallels a stream at a distance of 200 m and is 30 m above the water level in the stream. The subsoil consists of fine sand with a K-value of 5 m/day. Impermeable material occurs at a depth of 20 m. Groundwater occurs for most of the year at a depth of 6 m below the proposed infiltration strip, and it drains naturally to the stream. The infiltration rate of the effluent will be 0.2 m/day. What will be the maximum width of the infiltration area if the water table should not come closer than 0.5 m to the surface of the soil?

For the natural drainage flow, we have $D = 20 - 6 = 14$m and $H = 30 - 6 = 24$m. Thus the drainage flow can be calculated with equation (1) as $5 \times 14 \times 24/200 = 8.4 m^3$/day per in length of stream. During effluent infiltration, $D = 20 - 0.5 = 19.5$ m and $H = 30 - 0.5 = 29.5$ m. Thus we have

$$8.4 + WI = 5 \times 19.5 \times 29.5/200$$

which gives $WI = 5.98 m^3$/day per m length of stream or infiltration area. Since $I = 0.2$ m per day, the maximum width of the infiltration area is 29.9 m, or just about 100 ft.

Interception by Horizontal Drains

To allow proper time and distance of underground travel, horizontal drains for removing renovated water from a shallow aquifer should be placed a certain distance from the area where the wastewater enters the soil (Figure 2). The height, H_c, of the water table below the outer edge of the infiltration area can be calculated with the equation (Bouwer[9])

$$H_c^2 = H_d^2 + IW(W + 2L)/K \qquad (2)$$

where I is the infiltration rate, K the hydraulic conductivity of the soil, and the other parameters are as shown in Figure 2.

To design a given system, a certain location for the drain is selected and H_c is calculated with equation (2). If this does not yield the desired height of the water table below the infiltration area, the depth of the drain and/or some of the other variables (L, W, and I) are changed until a satisfactory value of H_c is obtained. Sometimes, an L-value less than the most desirable distance of underground travel may have to be accepted to obtain a workable system.

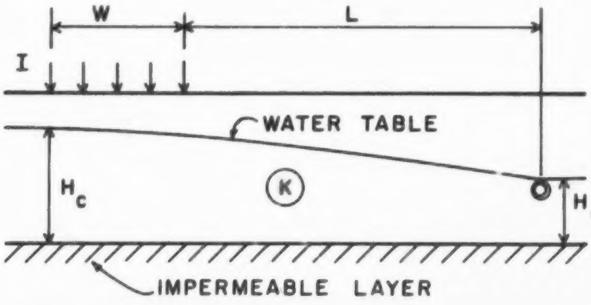

FIGURE 2. COLLECTION OF RENOVATED WATER BY DRAIN.

A similar calculation can be made if the renovated water is to be intercepted with a trench or open ditch. An example of a system of parallel infiltration basins and drains with drains closed below flooded areas to prevent short-circuiting was presented by Bouwer[9]. If drains are located midway between infiltration areas, essentially no native groundwater will enter the drains and only renovated water will be collected.

Example –

Renovated water is to be collected by horizontal drains which will be installed on both sides and at a distance of 50 m from a long infiltration basins. The drains will be at a depth of 2 m and impermeable clay occurs at 8 m depth. The soil is dune sand with K = 10 m/day. Experiments have shown that soil clogging will occur in the basin and that the infiltration rate will be about 0.15 m/day. What is the maximum width of the basin if the water table should be kept at least 0.1 m below the basin bottom?

Taking the symbols from Figure 2, we have:

$I = 0.15$ m/day,
$K = 10$ m/day,
$H_c = 7.9$ m,
$H_d = 6$ m, and
$L = 50$ m.

Substituting these values into equation (2) gives $W = 15.3$ m. Since the drains are on both sides of the basin, Figure 2 represents only one-half of the system. Thus, the maximum width of the basin is $2 \times 15.3 = 30.6$ m.

If, for the same conditions as above, the drain is to be located midway between two parallel infiltration basins which are 10 m wide and 100 m apart, and if the natural water table outside the basins is at a depth of 0.8 m and not to be affected by the infiltration and drainage system, what should be the depth of the drain?

We now have:

$I = 0.15$ m/day,
$K = 10$ m/day,
$H_c = 7.2$ m,
$L = 50$ m, and
$W = 10$ m.

Substituting these values into equation (2) gives $H_d = 5.94$ m, so that the depth of the drain midway between the basins should be $8 - 5.94 = 2.06$ m.

Interception by Wells

Renovated water can be completely intercepted by wells if the wells are located on a line midway between two parallel infiltration areas (Figure 3). If the system is managed so that the water table below the outer edges of the infiltration areas (AB) remains at the same level as the water table in the aquifer adja-

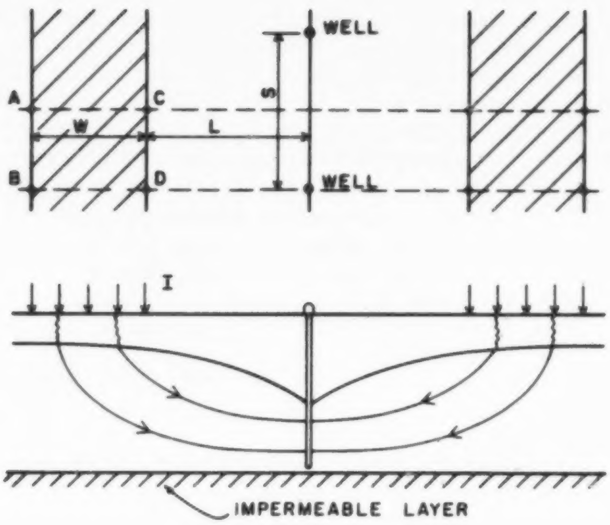

FIGURE 3. PLAN (TOP) AND CROSS-SECTION (BOTTOM) OF TWO PARALLEL INFILTRATION STRIPS WITH WELLS MIDWAY BETWEEN STRIPS FOR PUMPING RENOVATED WATER.

cent to the system, there is no hydraulic gradient to or from the wastewater renovation system and all water that has infiltrated as sewage effluent in the basins will be pumped as renovated water from the wells between the infiltration areas. To be safe, however, the water table below the outer edges of the infiltration area may be kept slightly below that in the adjacent aquifer. This will cause a slight gradient towards the wastewater renovation system, making it impossible for renovated water to move out into the aquifer.

The shape of the water table in a system like Figure 3 can be calculated with dimensionless graphs developed with an electrical analog (Bouwer[10]). One of these graphs shows that if $L/S < 0.5$ (see Figure 3 for symbols), the water table at D will be lower than at C because C is farther away from the wells. However, if $L/S > 0.5$, the water table at C will be essentially at the same level as at D. The same is true for the water table at A and B. The water table drop from AB to CD can be calculated with the equation.

$$H_i = IW^2/2T_e \qquad (3)$$

which is based on the assumption of horizontal flow (Bouwer[10]). In this equation, H_i is the water table drop from AB to CD, I is the average infiltration rate in the infiltration area (including any dry areas), W is the width of the infiltration strip, and T_e is the effective transmissibility of the aquifer for groundwater recharge. The effective transmissibility is less than the total transmissibility of the aquifer if the aquifer is relatively deep. This is because recharge flow systems have an upper, active zone where most of the flow is concentrated, and a deeper passive zone where water movement is only slight. The effective transmissibility depends on the width of the infiltration strip in relation to the height of the aquifer. The effective transmissibility can be evaluated from the response of the water table to infiltration, as was done for the Flushing Meadows Project (Bouwer[10]).

The draw-down of the water table from CD to the wells can be evaluated from a second dimensionless graph (Figure 4) which shows the dimensionless ratio $2WSI/T_W H_W$ in relation to L/S. The symbol H_W in this dimensionless parameter refers to the water table drop from D to the well. The symbol T_W is the transmissibility of the aquifer for the well-flow system. If the wells are completely penetrating the aquifer, the total aquifer transmissibility can be used. If the wells are partially penetrating, the appropriate correction factor must be applied (Todd[11]). The other symbols are the same as discussed for equation (3) and shown in Figure 3.

The graph in Figure 4 is based on the theory that the total well discharge is equal to the total infiltration rate, i.e., renovated water is pumped from the aquifer as fast as sewage effluent enters the soil. The use of equation (3) and Figure 4 to calculate the total drawdown of the water table will be illustrated by the following example.

Example –

Infiltration basins are located in two parallel strips 91.4 m (300 ft) wide and 243.8 m (800 ft) apart. Renovated water is pumped from wells located 152.4 m (500 ft) apart, midway between the strips. The average infiltration rate over the entire infiltration strip (including dry areas) is 0.183 m/day (0.6 ft/day). The effective transmissibility of the aquifer for the recharge flow system below the infiltration areas is 464.5 m^2/day (5,000 ft^2/day). The transmissibility of the aquifer for the flow towards the wells is 743.2

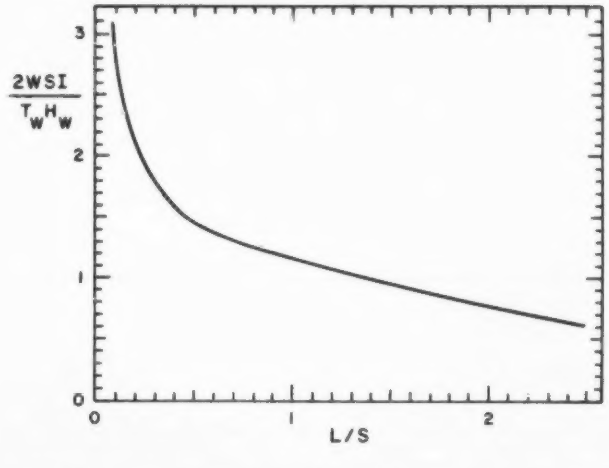

FIGURE 4. DIMENSIONLESS GRAPH FOR CALCULATING WATER TABLE DROP FROM CD TO WELL IN FIGURE 3.

m^2/day (8,000 ft^2/day). What is the water table drop from AB to the wells if renovated water is pumped from the wells at the same rate as the total infiltration rate of the secondary effluent?

Solution – The calculation will be done in English units with the end result converted in its metric equivalent. We have the following quantities

W = 300 ft
L = 400 ft
S = 500 ft
I = 0.6 ft/day
T_e = 5,000 ft^2/day
T_w = 8,000 ft^2/day

For this system, $L/S = 0.8$, so that the water table from A to B and C to D is essentially horizontal. According to equation (3), the water table drop from AB to CD is

$$0.6 \times 300^2/2 \times 5{,}000 = 5.4 \text{ ft}$$

To calculate the water table drop from CD to the well, the dimensionless parameter in Figure 4 is evaluated as 1.3 for the L/S-value of 0.8. Thus,

$$2WSI/T_wH_w = 0.8$$

which gives

$$H_w = 2 \times 300 \times 500 \times 0.6/8{,}000 \times 0.8 = 28.1 \text{ ft.}$$

Thus, the water table at the wells will be 28.1 + 5.4 = 33.5 ft or 10.21 m below the static water level in the aquifer outside the system of infiltration areas and wells. The discharge per well is

$$2SWI = 180{,}000 \text{ ft}^3/\text{day} = 935 \text{ gpm} = 59 \text{ liters per second.}$$

The minimum time and distance of underground travel for the renovated water in the system of Figure 3 will be for effluent that has infiltrated at point D. Underground detention times can be calculated from the equipotentials and streamlines (flow net), as shown in a previous paper (Bouwer[10]). To facilitate these calculations, equipotentials were presented for the flow system between CD and the well for different values of L/S, so that flow nets can be constructed and the shortest underground detention times can be estimated.

ECONOMIC ASPECTS

The economic aspects of high-rate land treatment can not be generalized because the cost depends on land cost, area needed, distance between treatment plant and infiltration area, and on the interception or collection system if the renovated water is to be reused or otherwise taken out of the aquifer. High-rate treatment on a large scale was estimated to cost about $4.3 per 1,000 m^3 ($5.3 per acre-ft or $16 per million gallons) (Bouwer[5]). This figure includes amortization of capital investment, operation and maintenance cost, and pumping the renovated water to the surface. The cost of equivalent in-plant tertiary treatment would be at least ten times as much.

When the land is purchased outright or is already owned by the municipality or other agency, an important economic aspect is increasing land value. Thus, if a land treatment system is eventually abandoned, the land will have considerable resale value, whereas with in-plant tertiary treatment, buildings, pumps, pipes, tanks, etc. depreciate and must be written off.

SELECTION AND DESIGN OF SYSTEM

The decision whether or not to use land treatment should be based on an objective evaluation of several alternatives. The system that is economically and environmentally the most attractive must be selected in a rational manner. Unlike conventional or advanced sewage treatment plants for which design criteria and manuals are readily available, the design and operation of land treatment systems (particularly high-rate systems) must be adapted to the local conditions of climate, soil, and hydrogeology. This requires not only the talents of the traditional sanitary engineer, but also those of the agronomist-soil scientist, the agricultural engineer, and the groundwater specialist.

Many existing land treatment systems have been described in the literature and the results and experiences obtained are of great importance in the design of new systems. Because of the many different conditions that can be encountered, however, it will always be advisable to start on a small scale, using a pilot or experimental project, before embarking upon any grandiose scheme, particularly in areas where previous experience with land treatment is unavailable. It will also be desirable to continue monitoring land treatment systems, so that undesirable performance can be corrected before it damages native groundwater or other natural resource.

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Land Application of Treated Sewage in the Mountain State

by
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Land treatment of municipal sewage is not considered feasible by the State of West Virginia. Among the reasons cited by state officials are the unique problems created by the topography, climate, and soil of the Appalachian Mountains. However, ample evidence exists which suggests that land treatment systems will not only work but will also save taxpayer's money.

One hundred thirty-nine communities in California's mountains utilize land treatment—most with a high degree of success.[1] Slopes in the treatment areas range up to 20°.[2] Most counties in West Virginia have over one-half their land in slopes under 20°. Therefore, experience in dealing with slopes in California can be applicable to those areas. However, West Virginia's five steepest counties have from 59 to 93% of their land sloping over 20°.[3] The respected firm of Bauer Engineering Incorporated of Chicago evaluated this problem in conjunction with a proposed sewage treatment system for the rebuilding communities on Buffalo Creek, and concluded that application of treated sewage to very steep slopes, 20° - 40°, was feasible. Stability problems were considered, and it was found that the generally horizontal rock layers underlying the soil would help prevent landslide of wet soil. The application rate would have to be limited to 1" per week.[4]

In regards to climate, West Virginia is subject to periods of heavy rainfall and freezing weather. This obstacle is overcome by providing storage facilities to hold sewage, as is done at Penn State. At Buffalo Creek it was estimated that 45 weeks a year would be suitable for land treatment.

The SCS has estimated that 1/3 of the soil, scattered throughout the Appalachians, is suitable for land treatment.[5] Soils with a heavy clay content are good for the overland flow method of land treatment, and better drained soils useful for spray irrigation. Geology, soils, and groundwater patterns must be thoroughly evaluated in choosing where and how to use land treatment.

West Virginia is 75% forested, with much of this being of relatively low value. Irrigation with sewage increases tree growth and the quality of wood fiber, without adverse effect on wildlife.[5] The Forest Service says that there is no surface runoff from heavily forested Appalachian slopes, so erosion should not be a problem if application rates are not too high.

The principal economic activity in much of West Virginia, coal mining, is not incompatible with land treatment. In fact, the state's numerous strip mines and coal refuse piles should be considered prime land treatment sites. Penn State experiments show that sewage effluent can be a valuable reclamation tool on abandoned strip mines.[6] Most of Chicago's sewage treatment sludge is now piped to stripped areas and this has been deemed very successful.[7] With many strip mine permits now being issued to large acreages (100 - 1,500) and fertilizer prices skyrocketing, sewage effluent should also become attractive for active operations.

The U. S. Forest Service now operates two little known land treatment facilities in West Virginia. At Camp Horseshoe, effluent is sprayed on a flat forested area; at Lake Sherwood, irrigation water trickles down a hillside. Because of their proximity to recreational streams, advanced treatment was required and land treatment was found to be the most economical alternative. According to Forest Service personnel, these land treatment systems are successful.

Some 70 cities in West Virginia will be required to go to advanced treatment. Most of these are very small, population 500 - 5,000, so that economy of scale for advanced treatment plants is impossible, but that acreage needs for land treatment are not excessive. The Buffalo Creek pilot project, proposed by the Army Corps of Engineers but rejected by the State of West Virginia, represented a 23% savings in total annual cost over an advanced treatment plant.[4] When projected to all the West Virginia projects requiring advanced treatment, over $1,000,000 a year in taxpayers' money could be saved by using land application.

The Army Corps of Engineers report concluded, "Development of an efficient land treatment program offers the only potential for achieving high level performance within the forseeable future in areas such as Buffalo Creek."[4] Our organization hopes that this view is given more serious consideration in the future by those planning and funding West Virginia's sewage treatment programs.

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